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NAVAL CIVIL ENGINEERING LABORATORY
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STUDY OF EQUIPMENT AND METHODS FOR REMOVING OIL FROM HARBOR WATERS

25 August 1969

An Investigation Conducted by

BATTELLE MEMORIAL INSTITUTE
Pacific Northwest Laboratories
Richland, Washington 99352

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ABSTRACT

A cost effectiveness analysis was performed for equipment, materials, and techniques for the removal of spilled petroleum products from the surface of port and harbor waters used by U.S. Naval craft. Effectiveness criteria, formulated for present methods and presently available equipment and materials, included speed, completeness, ease of operation, effect on marine life, and availability. Parameters for the effectiveness study were based on the petroleum products now in use or planned future use and a detailed review of the geographic, hydrographic, physical, and environmental characteristics of ports used by the U.S. Navy. The two most cost-effective systems for broad application were found to be mechanical recovery of spilled material by surface suction devices, supplemented by mechanical containment, and the application of chemical dispersants by pier- or vessel-mounted high pressure spray equipment. Recommendations included: the development of additional technology pertinent to petroleum product spills of concern to Naval [illegible] additional management planning and preparation for coping wi[illegible] [illegible]incidents; installation of equipment at Naval facilities to prot[illegible] [illegible]itive areas; and support of innovative development activities [illegible] methods for coping with petroleum spills.

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FOREWORD

This report summarizes research conducted by Battelle-Northwest for the Department of the Navy, Naval Civil Engineering Laboratory, under Contract No. N 62399-69-C-0028.

The research team comprised:

P. C. Walkup	Manager, Systems Design Development (Project Manager)
P. L. Peterson	Technical Leader, Marine Engineering Function (Recovery Systems Evaluation and Cost Analyses)
L. M. Polentz	Technical Leader, Systems Design Studies (Characteristics, Behavior, and Effects of Spilled Materials)
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Acknowledgment must also be given to the outstanding cooperation and assistance provided by the many interested parties. Special thanks go to NAVFAC regional sanitary engineers, Navy Base personnel, Federal Water Pollution Control Administration personnel and many manufacturers of commercial equipment and materials.

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STUDY OF EQUIPMENT AND METHODS FOR REMOVING OIL FROM HARBOR WATERS

1. INTRODUCTION

Many types of equipment, materials, and techniques have been employed to remove spilled petroleum products from the surface of harbor waters. The range of credible spill situations and petroleum products with high potential involvement suggests that no single system is likely to be completely effective. This study is intended to identify and describe the most cost-effective available systems consisting of present or new combinations of existing equipment, materials, and techniques. It is also intended to identify present deficiencies and recommend specific measures for future employment by the Navy to combat spills at Naval installations in ports and harbors in consideration of costs, effectiveness, speed, hazards, ecological effects, environmental and geographic factors, and physical features of the port or harbor. The study focuses on the major petroleum products in current use by the Navy or planned for future use.

The technical Summary and Conclusions section outlines the findings of this study, including recommendations. The Operational Procedures section is intended to assist the Navy in implementing the results of this study. The Discussion section is organized to present technical background on the petroleum products studied (Bunker C, Navy Special, JP-5 and a new Distillate Fuel) and their behavior and fate after spillage; characteristics of ports and harbors and a discussion of pollution regulations; formulation and analysis of effectiveness measurement, identification of candidate equipment, materials, and techniques, and evaluation of the effectiveness of candidate systems; identification and cost analysis of most effective systems; and definition of future work needed. Supporting information appended to the report includes detailed port and environmental data, procurement information on materials and equipment, effectiveness computation sheets for each candidate system, and illustrations of recommended systems and equipment.

2. TECHNICAL SUMMARY AND CONCLUSIONS

CHARACTERISTICS OF OIL AND ITS BEHAVIOR AFTER SPILLAGE

The materials in current use or planned for future use by the U. S. Navy are:

JP-5 Turbine Fuel
Distillate Fuel
Navy Special Fuel Oil
Bunker C Fuel Oil

Physical characteristics of these materials range from a low density, low viscosity material (JP-5) to a high density, high viscosity material (Bunker C). The Distillate Fuel, a new product which the Navy plans to employ in the next few years, physically resembles JP-5. The initial relative rates of spreading of these materials during the first hour or so after spillage on water are estimated to be:

Material	Rate of Spreading, ft/min, For 200 Gallon Spill
Bunker C	0
Navy Special	2.7
JP-5/Distillate Fuel	5.3

The behavior of these materials is described in the sections entitled Characteristics of Spill Materials and Behavior of Spilled Petroleum Products, pages 4-1 to 4-11. In summary evaporation rates after spillage would be very low for the residual materials (Bunker C and Navy Special) but would be quite significant for the lighter and more volatile materials. Evaporation rates under field conditions are highly dependent on air contact area, air velocity, and temperature. Up to 80% of spilled gasoline has been observed to evaporate in three hours at a temperature of 34 °F with very low surface wind velocity. The evaporation of the volatile products (JP-5 and Distillate Fuel) would be expected to approach such rates. For the other materials, evaporation would be minimal.

Rates of movement with surface winds would be expected to be about three percent of the wind velocity. Slicks would be expected to move at the same rates as prevailing surface currents.

Unrecovered oil will ultimately evaporate and be deposited on shore or be dispersed in the water. Unevaporated material will eventually undergo biological degradation at rates which depend on the microorganisms present, the availability of oxygen, temperature, and the degree of dispersion. These conditions vary so widely and quantitative relationships are so obscure that no meaningful rates of oxidation can be estimated.

EFFECTS OF SPILLED PETROLEUM PRODUCTS

The effects of spilled petroleum products are described and evaluated in the section titled Effects of Spilled Petroleum Products, pages 4-11 through 4-16. The following paragraphs summarize these findings.

Following a petroleum spill on waters, the risk of fire is minimal. Even when ignition has been purposely attempted, the loss of heat to the supporting water surface inhibits burning. Except for the first five or ten minutes following a spill of JP-5, there would be virtually no danger of fire from the four materials considered in this study.

Experience has shown considerable variance in oil spillage effects on marine life. Massive spills of refined petroleum products have been shown to cause extensive mortality of marine organisms. Spills of lesser magnitude can cause flavor tainting and condemnation of shellfish. Heavy oil slicks cause gross mortality of sea birds. Qualitatively, the damage to marine life for the spill sizes and materials considered in this study is expected to be quite modest for sites having a low spill frequency. For sites having a high spill frequency, the effects of chronic exposure of commercially and recreationally valuable marine areas can be severe. The most harmful material to marine life considered in this study is JP-5, followed by Distillate Fuel, Navy Special and Bunker C, in that order. The use of chemical dispersants for treatment can significantly increase toxicity.

The effects of oil on property are inverse to the effects on marine life. JP-5 and Distillate Fuel evaporate rapidly, are most readily dispersed, and are easily removed from surfaces. Damage by the heavier materials (Navy Special and Bunker C) is almost entirely esthetic. They are very difficult to remove from beaches, water craft, and structures, and represent the greater liability potential.

REFERENCE PORTS AND HARBORS

Domestic United States ports and selected installations outside the continental United States were characterized as to environmental characteristics and resources threatened by oil spillage. This characterization is described in the section entitled Reference Ports and Harbors, pages 4-16 to 4-19, and detailed supporting information is given in Appendix A. Sites which are most susceptable to oil spillage and have major Naval traffic are Massachusetts Bay, Narragansett Bay, Delaware Bay, Charleston Harbor, Port of Jacksonville, San Juan Harbor, Puget Sound, San Francisco Bay, San Pedro Bay, and Pearl Harbor. Table 1 lists parameter ranges for these sites.

TABLE 1. Parameter Ranges for Reference Ports and Harbors

	Parameter
Physical Characteristics	
Area, nmi^2	14 to 767
Shore Line, nmi^2	28 to 1157
Average Depth, ft	35 to 80
Environmental Characteristics	
Max. Current, knots	0.5 to 5.0
Mean Sea Temp, °F	50 to 78
Expected Significant Wave Height 90% of Time, ft	0.39 to 1.63
Resources	
Recreational Beaches	Yes
Boat Marinas	Yes
Sport Fishery	Yes
Commercial Fishery	No
Commercial Shell Fish	Yes

These summary data were used in deriving the effectiveness parameters and criteria for assessing candidate oil removal systems.

EFFECTIVENESS ANALYSIS

The section entitled Effectiveness Analysis, pages 4-20 to 4-53, describes the procedures, base data, candidate equipment, materials, and techniques, and their comparative effectiveness for removal of spilled petroleum products from harbor and port water surfaces. The analysis consisted of the following steps:

- Definition of effectiveness criteria and development of appropriate indices.
- Definition of parameter ranges.
- Identification of alternative systems for satisfying the criteria.
- Computation of the relative effectiveness of candidate systems under all combinations of parameters.

Effectiveness criteria were taken as: (a) completeness of removal of spilled material; (b) speed of application; (c) effect on pollution or hazard; (d) applicability to limited access areas; (e) sensitivity to natural phenomena; (f) toxicity to marine life, and (g) availability.

Parameters were defined with the environmental and physical characteristics of reference ports and harbors and the past

history of spillage incidents. They were:

Spill Size - 200 to 2000 gallons
Spill Frequency - 10 to 50 spills/year
Spill Material - JP-5, Distillate Fuel, Navy Special, and Bunker C
Harbor Flushing - Minimal to >0.5 knot current with adequate flushing.

Equipment, materials, and techniques potentially capable of meeting the criteria within the defined parametric ranges were classified as follows:

- chemical
- chemomechanical
- mechanical

Chemical treatment includes use of dispersants and materials which sink the oil, e.g. carbonized sand. Dispersants are normally sprayed on the slick, and agitation is required either at the time of application or subsequent to spraying.

Chemomechanical systems employ a chemical agent to sorb or gel the oil, and subsequent mechanical recovery.

Mechanical recovery methods include the use of rotating drums or endless belts, and gravity skimming devices employing weirs, suction pumps, and manual labor. Either self-propelled vessels or portable units which require auxiliary means for deployment are available.

Each system within these classifications was considered with and without containment. However, the addition of this capability improves the effectiveness of every system. Both hypothetical and existing systems of oil recovery were considered in the effectiveness analysis. Hypothetical systems were composed of the possible combinations of individual equipment pieces, materials, and techniques comprising existing systems. A total of 27 systems were considered as being potentially effective. Of these, 12 were clearly superior. These, in generic terms, were:

System	Effectiveness Index Total Score
1) Sorbents/manual retrieval plus containment boom.	144
2) Gellants/manual recovery plus containment boom.	144
3) Suction devices plus containment boom.	144
4) Chemical dispersants plus containment boom.	141-1/2
5) Sorbents/conveyor plus containment boom.	128
6) Gellants/conveyor plus containment boom.	128
7) Endless belt on water surface plus containment boom.	128

System	Effectiveness Index Total Score
8) Chemical dispersants applied directly to the slick.	126
9) Sorbents/portable suction device plus containment boom.	120
10) Rotating drum or endless belt (non-sorbent surface) plus containment boom.	112
11) Gravity skimmer or weir plus containment boom.	112
12) Rotating drum or endless belt (sorbent surface) plus containment boom.	112

COST EFFECTIVENESS ANALYSIS

Details of the cost effectiveness analysis are given in the sections entitled Effectiveness Analysis and Cost Analysis of Most Effective Systems, pages 4-20 to 4-53. Costs were estimated on a life cycle basis. The cost for each system was then divided by the effectiveness index for each system. These cost effectiveness ratios were then used as the basis of comparison of the postulated systems with the following results:

Parameters				Most Cost-Effective System
All assumed spill sizes	All petroleum products studied	All spill frequencies	Calm sea and minimal current	Suction device plus containment
			Moderate sea and $\leq 1/2$ knot current	Chemical dispersant with auxiliary agitation

It was concluded that Naval installations vulnerable to frequent spills should have both systems available. Under calm water conditions with minimal current, the suction device/boom system should be used. The chemical dispersant system should be used when water surface conditions are moderately severe or when significant currents exist ($\sim$1/2 knot), and where the use of chemical dispersants is not prohibited. Bunker C spills at temperatures below its pour point (30 to 60 °F) are not effectively treatable by any of the currently used equipment, materials, and techniques except for manual retrieval.

RECOMMENDATIONS

It is recommended that two general systems be employed for removal of spilled petroleum products from water surfaces of ports and harbors:

- Chemical dispersants supported by auxiliary agitation--under moderate water surface conditions and currents where not otherwise prohibited.

- Suction devices with containment booms--under calm conditions with minimal current present.

It should be recognized that the scope of this study was based on moderately sized spills recorded in connection with Naval operations in ports and harbors. Massive spills would undoubtedly require other strategies and techniques. It should also be recognized that this study was based on the present state-of-art. Successful conclusion of equipment and material development programs now in progress could substantially modify these recommendations.

It is believed that Naval installations which have experienced frequent spill incidents should have both systems available. Sites which are not so vulnerable may economize by providing the system which best suits the prevailing weather and hydrography.

A number of activities, whose implementation promises improvement of economy, effectiveness, or in preventing future spill incidents, were identified. We believe that these should be pursued--perhaps not only by the Navy, but by other organizations concerned with oil pollution in ports and harbors. To implement these activities, the following efforts should be undertaken.

- Develop additional treatment technology and study spilled oil behavior on harbor and port waters, including:
  a. Accurate methods for measurement or estimation of spill volumes. This is particularly important for treatments involving the use of dispersants, sorbents, or gellation agents in order to predetermine required application rates. Refinement of the "Blokker" technique for estimation of slick thickness after spillage, to take into account temperature, oil properties, and evaporation, appears to be a possible estimation method.
  b. Standardized effectiveness and bioassay tests for chemical dispersants which covers the range of possible spill materials. Current tests involve only Navy Special.
  c. Comparative evaluation of materials locally available at Naval installations and which are capable of serving as sorbers or agglomerants. This would be particularly valuable in the remote event of a massive spill, and should include the range of possible spill materials and such materials as straw, fly ash, pumice, volcanic ash, talc, and shredded bark.

- Provide detailed management planning and preparation for coping with spill incidents, including:
  a. Provide formal training programs for personnel charged with spillage countermeasures at all Naval installations. The program should be developed for each site, include conservation and hazards aspects, and be presented by recognized authorities.
  b. Develop a detailed action plan for coping with both moderate and massive spills of all petroleum products potentially involved in spillage at each Naval installation. Fall back positions should be included.
  c. Review each Naval installation to inventory materials and equipment available, and supplement as necessary.
- Install equipment at Naval installations to protect sensitive or vulnerable areas, structures, natural resources, and private property. This equipment should include:
  a. Permanent air barrier--mechanical boom combinations at fueling stations or other sites where operational considerations indicate frequent spillage.
  b. Surface water spray jet systems on structures having piling supports. By this method, spill material could be washed from under the structure to make it accessible for treatment.
- Support innovative development activities, perhaps in concert with other Government agencies or departments whose objectives would be to:
  a. Develop dispersants which require application rates approximating those for the more effective current materials but whose toxicity thresholds are on the order of 1000 ppm. Such materials are needed to accomplish "final polishing" after initial cleanup, by other methods, of spills of rapidly spreading materials such as Distillate Fuel and JP-5.
  b. Develop automated mechanical methods of collecting and removing, from water surfaces, oil agglomerates which have been formed by the use of sorbents.
  c. Develop flexible, readily deployable booms, fabricated of materials generally available to Navy installations and which have disposable skirting and covering.
  d. Develop <u>in situ</u> methods of producing polyurethane or other foams which have optimal void volume, pore size, and density, with regard to oil pollutants of concern to the Navy.
  e. Develop a rapidly deployable, integral, oil pickup-containment device.

3. OPERATIONAL PROCEDURES

The following paragraphs describe plans, procedures, and practices indended to assist the Navy in implementing the results of this study.

TRAINING AND ACTION PLANNING

Adequate training of operational personnel is essential for minimizing the cost of oil recovery and cleanup as well as assuring the most beneficial results from the equipment and materials employed. Operators familiar with the capabilities, limitations, and availability of existing equipment can avert accidents and minimize maintenance and repairs on equipment as well as cope with spills in the most effective manner.

The scope of necessary training includes emergency containment, operation of recovery or treatment equipment, and surveillance and prediction of slick movement.

Containment of released petroleum product as near to the source as possible is an essential first step in effective oil spill treatment. The lighter products, such as JP-5 and Distillate Fuel, spread into virtually uncontainable slicks in the absence of influences such as current and wind, within 20 to 30 min following release. Environmental factors, while perhaps reducing the rate of spreading, can cause the slick to drift into inaccessible areas or to structures, facilities, or beaches that can become contaminated and subsequently require substantial cleanup operations.

The rapid deployment of containment equipment can be effectively accomplished only by trained personnel. The training must include a presentation of the capabilities and limitations of each available boom, such as maximum towing speed, method of attachment or mooring, auxiliary equipment required, etc. In addition, the training should include practice drills in order that optimum deployment methods can be ascertained for various possible spill situations and locations within an area. Oil does not have to be present on the water surface for practice drilling of emergency containment procedures.

Equipment operators should be thoroughly familiar with the capabilities and limitations of equipment. Many unexpected events can occur during a spill or the ensuing cleanup operations, and the operator must know in advance how the equipment will react to a range of credible events. Training of personnel in the proper usage of equipment also assures maximum

effectiveness. For example, a crew operating a chemical dispersant system should be aware of the proper application ratio over a range of petroleum products and slick thicknesses. Insufficient application or subsequent agitation will often result in recoalescence of the dispersed oil, while excess application unnecessarily adds to the cost and possible toxicity.

Contingency planning at facilities where frequent spills occur naturally evolves after a number of spills are treated. The experience and planning of the facilities that do handle numerous spills might well be passed on to other less experienced facilities.

Contingency planning is not a readily definable term with respect to oil spill treatment. However, several aspects can be identified that are applicable to most installations. These include:

- Maintenance of a current tabulation which includes the amount of material on hand, status of equipment, and availability of emergency services to cope with oil spills.
- Establishment of up-to-the-minute sources from which information, pertaining to existing and expected weather and sea conditions and surface currents, can be obtained to permit prediction of slick destination and behavior. This information can further serve as a guide to system selection if alternatives are available.
- Identification of the most likely locations and times for spills to permit optimum storage locations of equipment and materials. Information of this nature is essential for consideration of permanent barriers to prevent oil spread or penetration.
- Evaluation of the facilities, resources, marine life and recreational areas, at or near each installation, that could potentially be affected by either an oil slick or dispersed oil. Further investigation should include the conditions that will cause the oil to reach the areas evaluated. This can indicate the most effective system (if a choice is available) under a given set of existing conditions and, further, identify areas at which secondary defensive measures are desirable.

EMERGENCY CONTAINMENT

Containment or encirclement of oil spills is highly desirable in almost every conceivable spill occurrence. The timeliness of deployment cannot be overemphasized. Fire departments often retain custody of booms because they can be available on a 24 hour/day basis, and the personnel are accustomed to reacting to emergency situations. The potential

fire hazard associated with volatile product spills further justifies the choice of a fire department crew for emergency containment. A slick that is quickly contained may not require immediate recovery.

An efficient spill reporting system is essential for effective containment. Ships' personnel must be encouraged to report any spill immediately, and the deployment of observers may be justified in installations that have frequent spills. The report should include the type of product, exact spill location, and an estimate of the volume. Emergency communications should simultaneously inform the containment crew and the fire department.

SELECTION OF SYSTEMS

The choice of the optimum oil spill recovery or treatment system is dictated by an evaluation of the combined cost and effectiveness. The two systems identified for general applicability to a broad spectrum of Naval installations were (a) chemical dispersants applied directly to the slick and (b) suction devices in conjunction with containment booms. The parameters for each installation must be examined to ascertain which of these systems best suits the conditions at that facility. For example, if rough water is common at a particular location, suction devices are not effective. Similarly, in areas of minimal currents or tidal flushing, the effectiveness of chemical dispersants is highly questionable.

The general classes of equipment or materials (such as chemical dispersants) includes a great variety of types and sizes available from various manufacturers. The size and capacity of mechanical equipment or support vessels should not be any larger than required for the particular application. The choice of size and capacity can be influenced by several factors:

- Limited access areas in proximity to spill locations (requires maneuverability).
- Anticipated frequency and volume of spills.
- Availability of existing vessels.

Several hundred products are available for chemical dispersion of oil products. A list of some of the more common is included in Appendix B. The proprietary nature of the formation generally prevents specific information concerning the exact composition, thus resulting in procurement of an unknown compound.

Many dispersants are not applicable to all types of petroleum products and the toxicity to marine life varies widely.

Information from manufacturers concerning toxicity, effective dispersion ratio, corrosion or personnel safety hazards is often overly optimistic or based on nonrepresentative tests. Thus, the product should be either tested on the entire range of petroleum products for both effectiveness and toxicity or information should be sought from unbiased sources (if these indeed do exist) concerning the above factors. Comparative tests of several products simultaneously and under the same conditions minimize the effect of experimental vagaries.

Any chemical product that is found effective should not be replaced by another without comparative tests of all pertinent aspects by the user.

Integrated oil recovery systems, such as those including a stationary oil retrieval device and storage receptacles fixed to the craft, have a disadvantage from the availability standpoint. If any mechanical failure occurs, such as engine or pump failure, the whole system is unavailable until the trouble is remedied. Damage to the surface vessel produces similar results. The periodic or unexpected maintenance on large vessels, such as LCM's, can render a system unavailable for extended periods. In areas where frequent spills occur, it would appear particularly desirable to make the mechanical recovery apparatus and storage receptacles semi-portable and thus enable transfer to another vessel in the event of mechanical breakdown.

USE OF EQUIPMENT

The manufacturer's operating and maintenance guides and recommendations should be followed unless the results are unsatisfactory. One aspect of personnel training should stress the importance of not deviating unnecessarily from the recommended guidelines.

The recommended method for application of chemical dispersants varies considerably in that some manufacturers recommend dilution of the dispersant and vigorous agitation of the slick during application, while others recommend application of the undiluted dispersant to the surface followed by a period of several minutes to allow penetration before agitation. The dispersants requiring an undisturbed penetration period are therefore not applicable to slicks in choppy waters.

Dispersants amenable to application in a diluted condition through high pressure nozzles (eductor systems) are probably best suited to utility around Naval installations. Nozzle pressures in excess of 200 psi are common and result in considerable turbulence upon striking the water surface. Auxiliary

agitation provided by fire hoses and the natural screw and hull wake of the surface craft also promote mixing. Dilutions of 10-50 parts water per part of dispersant are frequently employed.

Surface craft that dispense chemical dispersants need only deck space to accommodate the pumping equipment and storage space for about 12 barrels of the dispersant. Crews normally can be limited to two or three personnel, with one piloting the craft, another applying the spray, and the third tending the equipment.

Suction devices take various forms and therefore compatibility with surface vessels will vary. Generally, all types recover a considerable volume of water (up to 90%) in addition to the oil and large storage tanks are required (up to 10,000 gallons plus decanting capability). Surface craft employed for this purpose normally are in the 30 to 40 ft range. Two or three personnel are required for the crew. Some of the more recently developed suction devices might minimize the required storage capability, because they recover greater percentages of oil, and thus permit smaller support vessels. Suction devices normally can be made semi-portable.

Two useful accessories are desirable for use with floating containment booms, if available for the type used. These are (a) a buoyant "bridge" which will support suction hoses extended across the boom and (b) a device which permits the boom to be drawn over it to concentrate the oil slick by reducing the enclosed area. Inflatable booms will not normally endure such handling operations and are therefore not recommended for emergency containment. A suitable air supply is also often a problem in open water areas. Some booms can be folded accordion-wise to decrease the enclosed area on the water surface.

SECONDARY DEFENSES

The prevention of oil penetration into inaccessible areas, such as under piers, can be effected by any of several methods. However, the protection of all of the facilities and inaccessible areas around a typical Naval facility may not be economically feasible. Two relatively inexpensive systems do have merit for secondary containment. The first employs discarded hawsers that can be stored along the pier and easily deployed from the pier. After contamination, they could be discarded. Discarded fire hose can be used for the same purpose, but an air supply is required. The second method is a normally passive system that employs a perforated pipe mounted above the water surface

on the inside surfaces of piling. One end would be connected to a water supply. If properly designed, water jets provide a satisfactory barrier to surface oil. The pipe might require provisions for vertical excursions in harbors where considerable tidal fluctuation exists.

Another type of secondary defense might be the provision of discarded hawsers to nearby boat marinas or other, similar facilities, such as recreation beaches, that might require costly restoration if contaminated. The owners could be notified if it appeared that oil pollution was imminent. This type of cooperation promotes good public relations in addition to potentially averting costly pollution.

DISCUSSION

CHARACTERISTICS OF SPILL MATERIALS

Four fuel oils have been considered in this study: Bunker C Fuel Oil, Navy Special Fuel Oil, Distillate Fuel, and JP-5 Turbine Fuel. The published properties of these fuels are listed in Table 2.

Bunker C Fuel Oil is the principal industrial boiler fuel oil. It is also known as No. 6 fuel oil and PS400 fuel oil, is a commercial product, and there is no military specification for it. It is a residual oil, i.e. it is what is left after the more volatile components have been distilled out of the crude oil. Some of the original contaminants, such as sulfur, remain in the residual oil. Its characteristics can vary rather widely and depend upon the properties of the crude oil from which it is extracted. It is a very viscous, tarry oil which is heated to reduce viscosity before pumping. It is a heavy oil, and, in some cases, may have a specific gravity as large as 1.07 at 60 °F. A representative value for the specific gravity of sea water at 60 °F is 1.025.

The characteristics of Navy Special Fuel Oil are given in Military Specification MIL-F-859E, Amendment 2, 4 August 1967, "Fuel Oil, Burner." It consists of a hydrocarbon (petroleum) oil with no additives.

The characteristics of the Distillate Fuel are given in Military Specification MIL-F-24376 (SHIPS), 27 January 1969, "Fuel, Reference, and Standard Distillate." It is a petroleum distillate with chemical additives which may include any or all of the following:

Antioxidant	9.1 g/100 gal fuel (U.S.)	Maximum
Metal deactivator	2.2 g/100 gal fuel (U.S.)	Maximum

The characteristics of JP-5 are given in Military Specification MIL-T-5624G, Amendment-1, 21 November 1966, "Turbine Fuel, Aviation, Grades JP-4 and JP-5." This fuel is a high flash-point kerosene required by the U.S. Navy primarily for carrier operations. Very few, if any, commercial turbine fuels satisfy the JP-5 specifications. JP-5 comprises the basic petroleum base (high flash-point kerosene) and a group of chemical additives which may include any or all of the following:

Antioxidant	9.1 g/100 gal fuel (U.S.)	Maximum
Metal deactivator	2.2 g/100 gal fuel (U.S.)	Maximum
Corrosion inhibitor	18.2 g/100 gal fuel	

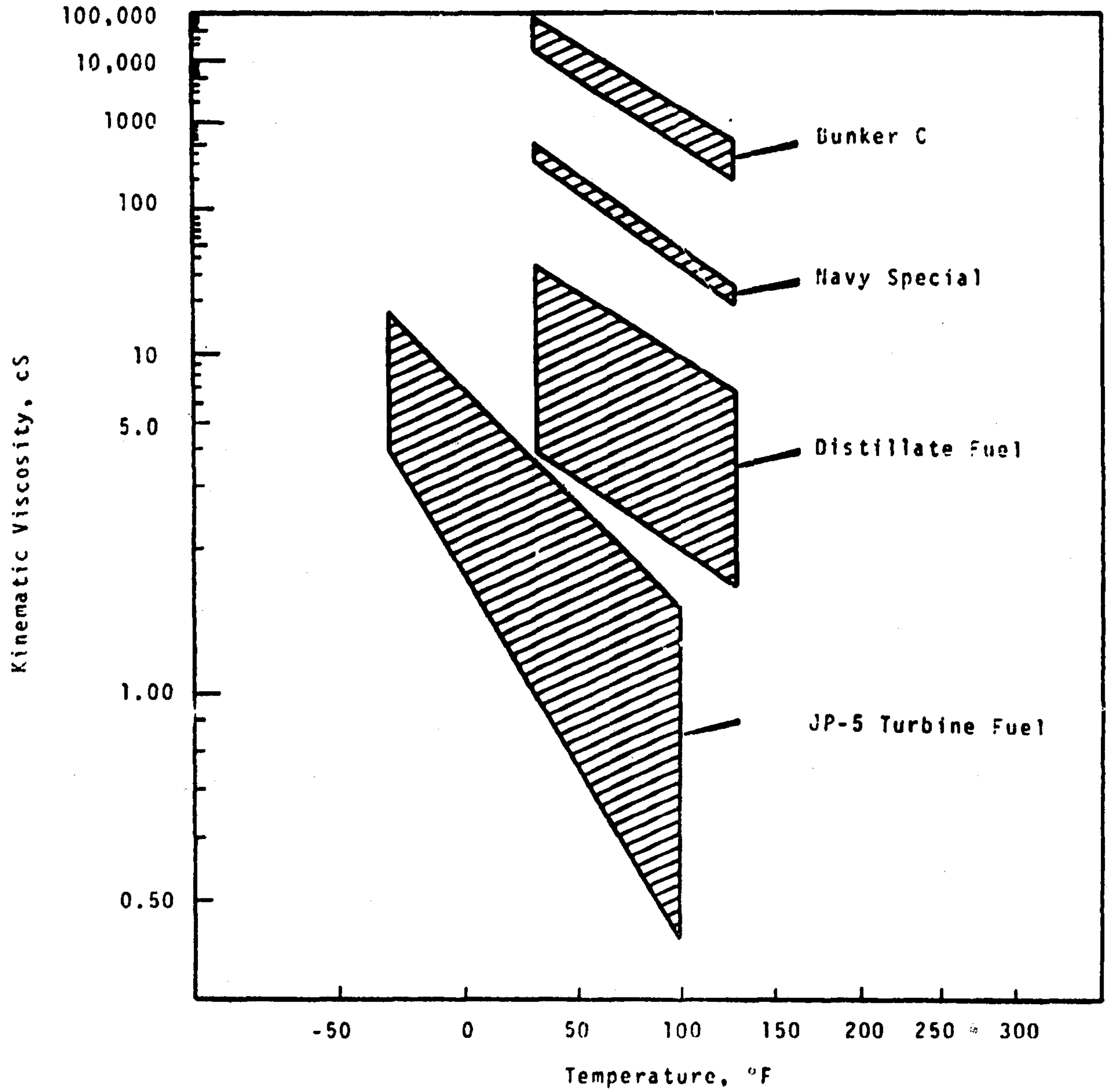
TABLE 2. Petroleum Product Properties

	Bunker C Fuel Oil	Navy Special Fuel Oil	Distillate Fuel	JP-5 Turbine Fuel
Gravity, °API	1-10.8	11.5 min.	27 min.	36-48
Specific Gravity 60/60	1.067-0.994	0.989 max.	0.893 max.	0.845-0.788
Flash Pt., min., °F	--	150	150	140
Viscosity				
SUS @ 85 °F	--	225 min.	--	--
SUS @ 122 °F	--	225 max.	--	--
SSF @ 122 °F	125-200	--	--	--
Kinematic,				
cS @ 100 °F	--	--	2.0-10.0	--
cS @ -30 °F	--	--	--	16.5 max.
Fire Point, °F min.	--	200	--	--
Flash Point, °F min.	--	150	--	--
Freeze Point, °F max.	--	--	--	-51
Explosiveness, % max.	--	50	50	50
Pour Point, °F	30-60	15	20-30	--
Aromatics, vol% max.	--	--	--	25

Representative variations and ranges of viscosity and specific gravity with temperature for the four petroleum products considered are shown in Figures 1 and 2. The ranges of viscosity and specific gravity have been estimated from data obtained from suppliers and in literature of suppliers of some of the different products.

BEHAVIOR OF SPILLED PETROLEUM PRODUCTS

The edge of an oil slick can move in two ways--the slick can spread out and cover more area, and it can move as a unit under



<u>FIGURE 1.</u> *Range of Viscosity Versus Temperature for Bunker C, Navy Special, Distillate Fuel, and JP-5 Turbine Fuel*

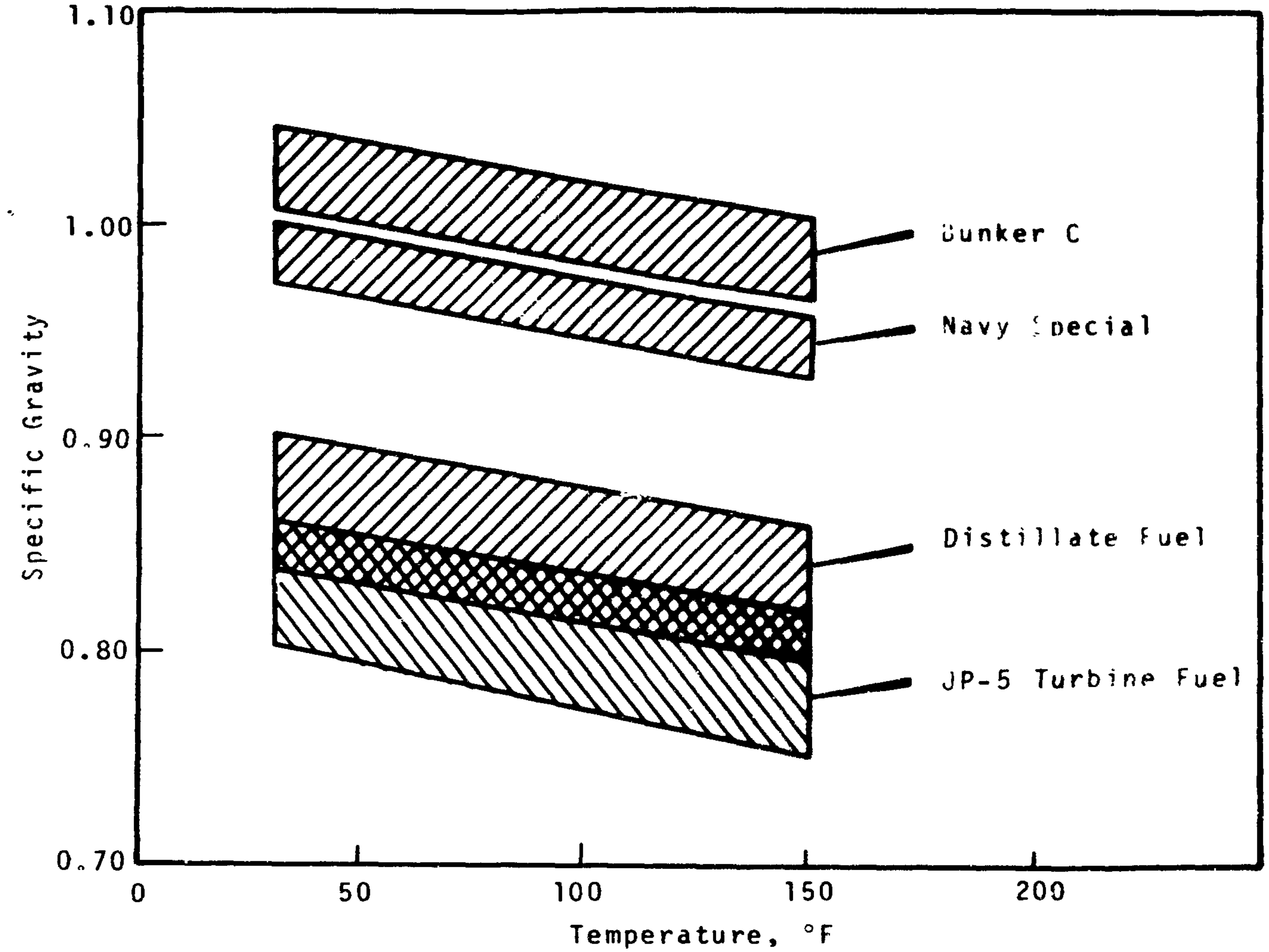


FIGURE 2. *Range of Specific Gravities Versus Temperature for Bunker C, Navy Special, Distillate Fuel, and JP-5 Turbine Fuel*

the influence of current or wind. The movement of the edge of the slick would equal the algebraic sum of the two components.

Spreading

Very little information is available in the literature on the spreading of large quantities of oil. The dearth of information is due, at least in part, to the strong public objections to the pollution which would result from performing large-scale experiments with petroleum on bodies of water. Some small-scale experiments have been conducted, however, and their results have contributed to a knowledge of the mechanics of spreading.

Observations have been made of the spreading which followed large, accidental spills.

Berridge,[1] et al investigated the rate of spread of a homogeneous oil slick for a group of crude oils with specific gravities ranging from 0.829 to 0.896. Their work indicated that the thickness of the slick tended to keep reducing, and the area increasing, until the thickness of the slick, for the oils tested, reduced to 0.0008 to 0.0012 in. The time required for a spill of 100 m^3 (26,400 gal) of oil to reduce to a slick of that range of thickness was 27.7 hours. They also observed that, for their samples, the slicks became distorted and moved bodily at speeds greater than the rate of spreading when the wind velocity reached 3 mph (4.4 ft/sec). In addition, they verified many of the findings of Blokker[2] and modified the equation (that he developed) relating slick radius and time to give a relationship for slick thickness vs. time--

slick thickness = $k/t^{2/3}$ where t = sec, slick thickness = cm, and $k = (v/\pi)^{1/3} \left[\dfrac{\rho w}{3\rho_o(\rho_w - \rho_o)K_r}\right]^{2/3}$

where v = volume of oil, cm^3

ρ_o = density of oil, g/cm^3

ρ_w = density of water, g/cm^3

K_r = a constant for a given oil

This relationship shows that the tendency for the oil slick to expand is, in part, a function of the difference in the densities of the oil and the water. As the difference approaches zero (as for a Bunker C Fuel Oil) the spreading force also approaches zero.

Blokker also determined that the rate of spread of a homogeneous oil slick is approximately proportional to the instantaneous

mean layer thickness. The spreading rate is also influenced by the viscosity, surface tension, interfacial tension between water and oil, density, chemical composition, pour point of the oil, current, and, as previously noted, wind speed.

The value of the pour point of an oil may have a profound influence on its spreading characteristics. An oil with a pour point higher than the temperature of the water, as could be the case with some Bunker C's, would form a semisolid mass that would have very little tendency to spread, particularly if its specific gravity approached that of sea water.

Both Blokker and Berridge concurred in the finding that spreading velocity is not a direct function of the viscosity of the oil as might have been expected. The influence of viscosity is relatively small, especially during the initial stages of the spill. Blokker, for example, noted that the time required for spilled oil to spread out to a slick of 2 cm thickness was very short, on the order of one minute for 100 m^3 for spills of oils with viscosities ranging from 0.8 to 490 cP at 20 °C. Berridge, et al, found, as previously noted, that the thickness of the slicks resulting from 100 m^3 spills of oils with viscosities ranging from 4.13 to 25.0 cS at 100 °F was fairly uniform after 27.7 hours.

Movement with Winds and Currents

An oil slick, or a blob of high-density oil, will move as a unit under the influence of water current or wind velocity. The oil will move at the same velocity as the water current when conditions have stabilized, providing no other forces are acting. The relationship of oil slick velocity to wind velocity is not so simple, however, and different investigators have arrived at different conclusions.

Brockis(3) quotes the results of a series of experiments carried out in Japan, coordinated by the Maritime Safety Agency. They determined that the oil slick moved with the wind at a rate of about 4% of the wind speed. Smith(4) reports that the results of a series of careful observations of wind velocity and oil slick movement, taken at 6-hr intervals from a land meteorological station, indicated an average rate of oil slick movement equal to 3.4% of the wind speed with the movement in essentially the same direction as the wind. He also quoted results obtained by Hughes(5) who found that plastic envelopes floating close to the surface of the Atlantic Ocean moved parallel to the direction of surface wind at 3.3% of the wind speed. A Weather Bureau meteorologist estimated that, in the case of the Santa Barbara Channel Oil-Pollution Incident, that the oil slick drifted

downwind at a rate equal to 10 to 20 percent of the surface wind speed.(6) He also stated "... instances of skin layer shear were noted with surface oil moving rapidly past nearby stationary free floating debris suspended less than half an inch below the water surface."(7)

For steady-state conditions, the ratio of slick speed to air speed can be estimated analytically by making a few simplifying assumptions. If we assume that the oil slick is a large, flat plate, floating on the surface of a body of water, the body of oil will tend to move if a wind blows across it. The wind, passing over the surface of the oil, will exert a drag force on the top of the oil. At equilibrium conditions, this drag force will be opposed by an equal and opposite drag force exerted by the water on the bottom of the oil mass. For an estimation of the relationship between speed of movement of the oil mass and the speed of the wind, the two drag forces can be equated. For skin friction, drag force, $D_F = C_F A \rho v^2/2$ where C_F = skin drag coefficient, dimensionless, ρ = density of fluid, slugs/ft^3, A = area of surface, ft^2, and v = velocity of fluid relative to object, ft/sec. C_F is a function of Reynolds Number, (Re), and, for turbulent flow, $C_F = 0.074/(Re)^{1/5}$ where $Re = \rho Lv/\mu$, where ρ = fluid density as before, slugs/ft^3, v = velocity, ft/sec, μ = absolute viscosity, lb sec/ft^2, and L = length of surface in the direction of movement, ft.(8) The above relationship is valid for drag force on one surface for Reynolds Numbers greater than 500,000.

For air at 60 °F,

$$\mu_A = 0.0175 \text{ cps} = 3.67 \times 10^{-7} \text{ lb sec/ft}^2$$

$$\rho_A = 0.00233 \text{ slugs/ft}^3$$

For sea water at 50 °F,

$$\mu_W = 1.5 \text{ cps} = 3.14 \times 10^{-5} \text{ lb sec/ft}^2$$

$$\mu_W = 1.985 \text{ slugs/ft}^3$$

$$Re_{Air} = 0.00233\ Lv_A/3.67 \times 10^{-7} = 6{,}360\ L \times v_A$$

$$Re_{water} = 1.985\ Lv_W/3.14 \times 10^{-5} = 63{,}200\ L \times v_W$$

If we assume an oil slick 100 ft long, then the air velocity would have to exceed 0.80 ft/sec (0.47 knots) and the velocity of the oil slick in the water would have to exceed 0.080 ft/sec (0.047 knots) for the Reynolds Numbers to exceed 500,000. The two velocities would have to exceed these values for the movement of the oil slick to be of interest, so we can assume turbulence at both water and air interfaces.

Drag Air = Drag Water

$$D_A = \frac{0.074}{(6{,}369\ Lv_A)^{0.2}}\ A\ \ \rho_A\ v_A^{\ 2}/2 = 1.495 \times 10^{-5}\ Av_A^{\ 1.8}/L^{0.2}$$

$$D_W = \frac{0.074}{(63{,}?00\ Lv_W)^{0.2}}\ A\ \ \rho_W\ v_W^{\ 2}/2 = 8.04 \times 10^{-3}\ Av_W^{\ 1.8}/L^{0.2}$$

The areas will be the same, top and bottom, and the lengths will be the same. The drags will be equal.

$$1.495 \times 10^{-5}\ Av_A^{\ 1.8}/L^{0.2} = 8.04 \times 10^{-3}\ Av_W^{\ 1.8}/L^{0.2}$$

$$v_A = v_W \times 538^{1/1.8} = 33\ v_W$$

or speed of oil slick in water = 3.0% of air speed.

This is a simplification of the actual situation, but it does tend to substantiate, from a theoretical standpoint, the findings of the TORREY CANYON investigators,(4) Hughes,(5) and the Japanese investigators.(3)

One other factor that affects the direction of travel of an oil slick is the component due to the Coriolis acceleration. If the wind has a north or south directional component, the oil slick will not move in the exact same direction as the wind but will veer off at a slight angle due to its change in latitude. In the northern hemisphere any southerly wind-induced movement will be accompanied by a slight westerly component of the oil-slick velocity. A northerly component in the wind velocity will produce an easterly drift. In the southern hemisphere the drift components of the velocity will be reversed, i.e., south wind--eastward drift and northward--westward drift.

The estimate of oil-slick speed equal to 10 to 20% of air speed made by the meteorologist(6) was evidently more of a guess based on visual observations. That estimate does not appear to have been based on measurements as was the estimate made by the TORREY CANYON investigators. Moreover, the meteorologist's observation appeared to include the effect of spreading as well as movement, and this could be applied to the movement of the periphery of an oil slick due to the combined effects of spreading plus slick movement.

Based on the results of the different investigators reviewed above, coupled with the theoretical analysis, it would appear that the speed of movement of an oil slick as a unit, due to the drag force exerted by a wind blowing across its surface, would be in the range between 3 and 4% of the wind speed.

The rate of spreading of an oil slick in a harbor, and its resulting thickness, can be quite different from those in an open sea. In a harbor the water is often contaminated, or becomes contaminated by surface-active substances in the spreading oil. In these cases, the thickness of the oil slick will tend to be greater than would be the case on a clean-water surface. In such a case the oil slick may reduce to 0.040 to 0.080 in. in thickness, and then the reduction in thickness may stop or continue at a slower rate. At the closed end of a harbor, wind may cause a considerable increase in the thickness of an oil slick. An 8-knot wind, for example, may keep a layer of oil that is trapped at the end of a harbor at a thickness of 1 in., according to Blokker.

Another very important factor in estimating the rate of spreading of a contaminant in a harbor is the effect of the characteristics of the particular harbor. The difference in the rate of dispersal of a dye released in different harbors was noted by Fisher(9) in his study of the rate of dispersal of a quantity of Rhodamine-B dye simulated contaminant released in the strait at Mare Island, California. Fisher found that an equation developed by Sir Geoffrey Taylor(10) provided a reasonably accurate estimate of the concentration to be expected at a given time and location in an open channel such as the Mare Island Strait. The relationship for the concentration at a given time and at a distance from the discharge point equal to the current velocity multiplied by time after release, reduces to

$$C = \frac{M}{2S\sqrt{\pi K t}}$$

where: C = concentration of contaminant

M = initial mass of contaminant

S = cross-sectional area of channel through which contaminant has spread

K = coefficient of diffusion

t = time after release of contaminant

For a given set of conditions, then, C is proportional to $K^{-1/2}$ where K depends upon harbor conditions, point of release, and time after release. Values of K for different harbors, determined by tests, vary widely. Representative values for different harbors and conditions are given below.

	K, ft^2/hr
Mare Island Strait, immediately after release of contaminant	517
Mare Island Strait, ebb current flow	25
Carquinez Strait	4.9×10^4
Pearl Harbor	40 - 160
James River	10^4 - 10^7
San Diego Bay	10^5 - 10^6

The average value of K for the Mare Island Strait, as determined from the tests reported by Fisher, equalled 270 ft^2/hr. Comparing this with the average K reported for James River of 5.005×10^6 gives differences for the maximum concentration at a point, other factors considered equal, in the ratio of 0.0608/0.000447 or 136:1.

From the reported experiments and theoretical analyses, it is deduced that the rate of spreading of an oil slick in a still harbor will go through three phases. The first spreading phase will last less than a minute for a 200 gal or 2000 gal spill. At the end of this phase the three lighter fuel oils will have spread out so that the thickness of the slick is less than 2 cm (0.788 in.). At this time the area covered by 200 and 2000 gal spills would equal 408 ft^2 and 4,080 ft^2 respectively.

The second phase of spreading will take place according to the Blokker relationship. During this phase, the JP-5 will initially spread faster than the Distillate Fuel which will, in turn, spread faster than the Navy Special. As the thickness of the slick decreases, however, the spreading force also decreases, so the rate of spreading of the JP-5 will reduce with time more than will the rate of spreading of the heavier oils after the initial spreading. After the lapse of 24 hr, the slick thicknesses and areas of the three lighter fuel oils will be nearly the same. At this time, too, the spreading rates will again approach one another, and the oil will reduce to film thickness during this third phase.

The effect of harbor currents and winds can overpower the effects of spreading during phases two and three. The configuration of the harbor, the amount of contaminants already in the water, the speed of the current, and the space available for the spreading of the oil slick can all have a very important bearing, but none of these can be predicted in advance.

The foregoing summary pertains only to JP-5, Distillate Fuel, and Navy Special. The Bunker C, depending upon its density and pour point, may spread little or not at all.

Fate of Unrecovered Material

Oil which is not recovered from the water may remain either dissolved in the water (a small amount), on the surface or suspended in the water, adhering to structures or rocks, mixed with the sand at the shoreline, or on the bottom of the sea if it has been sunk with a sinking agent. The small amount that is in solution will largely be dissipated rapidly by current and tides, though residuals may persist for many weeks in a closed area such as a bay or harbor. Oil which has been mechanically sunk to the bottom will largely break loose, little by little, and rise slowly to the surface. This oil, the oil remaining in the water, and that adhering to structures or shore, will be gradually degraded biologically.

Report of an extensive study by ZoBell[11] concluded that, "Virtually all kinds of oil are susceptible to microbial oxidation. The rate of such oxidation is influenced by the kinds and abundance of micro-organisms present, the availability of oxygen, temperature, and the dispersion of the oil in water. Microbial oxidation is most rapid when the hydrocarbon molecule is in intimate contact with water and at temperatures ranging from 15 to 35 °C; some oxidation occurs at temperatures as low as 0 °C. An average of one-third of the hydrocarbon may be converted into bacterial cells, which provide food for many animals. The remaining two-thirds of the hydrocarbon is oxidized largely to CO_2 and H_2O. In the marine environment, oil persists only when protected from bacterial action.

Based upon rates at which marine bacteria have been observed to oxidize various kinds of mineral oils under controlled laboratory conditions and upon information on the abundance of bacteria in the sea, it is estimated that oil might be oxidized in the sea at rates as high as 100 to 960 mg/m^3 day or 36 to 350 g/m^3 year.

In summary, if environmental conditions, (nutrients, temperature, and oxygen availability) are satisfactory, and if suitable microbial populations are present, oil will be degraded in the ocean. However, the rates of hydrocarbon degradation are slow when compared with those of the oxygenated derivatives. There has been much speculation recently about the ability of highly specific cultures to rapidly degrade oil spills, yet a dearth of specific information is evident.

EFFECTS OF SPILLED PETROLEUM PRODUCTS

Inflammability

A risk of fire occurs primarily when the concentration of hydrocarbon vapor in the air lies within the range of inflammability. A definite fire danger would exist with spilled

gasoline, a light crude oil, or a wide-range aviation turbine fuel. JP-5, however, is a high-flash-point turbine fuel and would present little danger after the first five or ten minutes following the spill. The danger of fire after that time could occur from pieces of wood or other material caught in the oil slick and which could act as a wick. In such a case, however, the fire would burn only at the wick. The large amount of water would act as an effective coolant and prevent heating of the oil layer surrounding the wick to the vaporization temperature. It is reported by Blokker(2) that layers of products such as kerosene, gas oil, lubricating oil, and fuel oil on water cannot burn at all without a wick. It has also been reported by Diedericksen(12) that oil on the sea in a thickness of less than about 3mm (0.118 in.) will not burn. The difficulty of igniting spilled oil was demonstrated in an experiment reported by Brockis(3) in which the use of a flame thrower was required to ignite Iranian crude five minutes after a spill. It should be remembered here that a crude oil contains light fractions and is definitely more inflammable than any of the fuel oils being considered. Another study reported that weathered oil is difficult to ignite and poses no real fire hazard.(6)

Except for the first five or ten minutes following a spill of JP-5, there would be very little danger of fire from spills of any of the four subject oils.

Effects of Oil on Marine Life

The greatest damage to marine and wildlife in past spills has been to birds. Oil from the Torrey Canyon killed tens of thousands of sea birds.(13) Other investigators reported that "Pollution by the 'Torrey Canyon' oil was found to have little biological effect apart from the tragic destruction of sea birds." A study of the effects of the Santa Barbara Channel oil spill concluded(6) that there were no observed, significant, acute oil kills of intertidal species, and that crude oil by itself is not highly toxic to macro fauna and flora.

Numerous studies of the effects of spilled crude oil were made during the Santa Barbara Channel oil spill. Generally, the consensus of the investigators was that crude oil, by itself, is not particularly harmful to marine life except for birds. The California State Department of Fish and Game studied the results of oil damage on Anacapa Island, a national refuge.(14) The conclusion was that losses to the island's intertidal life should not exceed 5 to 10 percent and that subtidal life should be unharmed. Another study was made of the effects of the oil spill on eggs and larvae of different fish. All samples appeared normal.(15,16) A survey of the effect on the fish population was

made. No noticeable effect was determined.[17] A study was also made of the effects of the spill on the health of the kelp beds in the channel area. Dr. W. J. North, an expert in the biology and utilization of the giant kelp (Macrocystis) reported that the kelp beds were unharmed.[18]

A review of the effects of a 2,000 ton diesel oil spill onto a one-mile stretch of coastline in the Gulf of California, however, showed that this refined oil was quite harmful to shellfish, kelp, and weed-grazing animals. Eight years after the spill, harmful effects were still apparent.

Other spills of petroleum showed potential harm to marine ecology. For example, a 10,000 ton crude oil spill on the shore of Guanica, Puerto Rico, resulted in extensive damage, and a variety of fish were found dead in the area as a result.[19] Large numbers of lobsters, crabs, sea urchins, starfish, sea cucumbers, snails, clams, octopi, abalone, and squid also died.

Experiments conducted on young shad showed that gasoline was relatively toxic.[20] Diesel oil was slightly less toxic as the fish could tolerate a 20% greater concentration of diesel oil with comparable results. Bunker C Fuel Oil was relatively non-toxic, i.e. it required 20 to 30 times the concentration of Bunker C as compared with gasoline to produce comparable toxicity.

Oil pollution also causes an oily taste in clams, crabs, and oysters. An oil spill in Yaquina Bay, Oregon in 1963 caused a cessation of both sport and commercial crab fishing.[21] An oily taste in oysters may result from a concentration of as little as 0.01 ppm of oil,[22] and the oily taste may be retained for four to six months. Quahogs are also given a repugnant taste by oil in the water, though they can withstand fairly heavy concentrations without dying. European mussels also become tainted by oil pollution.[23]

The effect of the lighter hydrocarbon liquids on clams was also illustrated by a case in 1963 when an oil and gas barge dumped 2,300,000 gallons of gasoline, diesel fuel, and furnace oil into the ocean near Moclips, Washington. Thousands of razor clams were killed by the pollution as well as a number of horse clams and Dungeness crabs.[24,25]

It would appear that relatively little harm to the marine ecology in a harbor, except for the birds, would result from a spillage of Bunker C or Navy Special, unless it was in a large enough amount to completely inundate the area. Any birds alighting on an oil slick would probably die unless carefully cleaned and rehabilitated. Cleaning and rehabilitation are time consuming, expensive, and relatively ineffective. Extensive efforts to save birds contaminated by oil from the Torrey Canyon resulted in success in only some 10% of the cases.

Spillage of Distillate Fuel could be expected to result in some harm to fish, shellfish, and other marine life. Much greater damage could be expected to result from a large spillage of JP-5 turbine fuel. This is a lighter hydrocarbon than the others considered, and it will spread more rapidly. It will also permeate the water to a much greater extent. It could be counted on to contaminate clams and other seafood fauna in the area and make them unfit for human consumption for as long as six months after the time the spilled oil was cleaned up. It could also cause a high mortality of clams and oysters in the tidal area. In especially high concentrations, it would also kill fish, crabs, and lobsters. In addition, JP-5 contains chemical additives. A careful search of the literature revealed no information regarding the toxicity of the additives used in JP-5. It is expected that, in the extremely small quantities in which they would be injected into a harbor, their effect would be slight. Testing would be needed to determine whether or not they could be accumulated in a sea animal to form a dangerous concentration at some later date.

Effects of Spilled Oil on Property

The effects of spilled oil on property are almost inversely proportional to their effects on marine life. JP-5 will leave very little residue on beaches, vessels and structures with which it comes into contact. It can usually be easily washed off surfaces with water, or water with a small amount of detergent added. The slight residue which it leaves on sand and beaches goes away fairly rapidly under the influence of natural oxidation and bacterial action. The heavier fuel oils, however, present a vastly different situation. The effects of the two heavy fuel oils are much the same except that the Bunker C is worse than the Navy Special since it is heavier and more viscous and adheres to a surface more tightly once it becomes attached.

Removing Bunker C Fuel Oil from pilings, ship hulls, buildings, or rocks is an expensive and time-consuming operation. The damage is almost entirely esthetic except when the heavy oil plugs openings in a structure or hull, and this means that its removal must be complete to be successful. Bunker C is relatively resistant to the action of detergents and solvents since it is quite dense and very viscous. Sand blasting has been used successfully in cleaning it off rocks, but cannot be used on fiberglas hulls or wooden structures. Steam cleaning or hot water is also limited in application.

All four of the petroleum products considered are very harmful to objects made of natural rubber and some plastics. The damage in these cases results from chemical and/or solvent action and the danger is greater from JP-5 and Distillate Fuel than from the heavier, more viscous fuel oils.

Effects of Treatment Agents on Marine Life and Property

The treatment agents utilized in past oil spills, and propounded for use by their manufacturers, are of two general types--detergents to promote emulsification, and sinking agents.

The effect of detergents on property is minor and no studies on the use of detergents in treatment of oil spills report on damage to property from the use of detergents. However, extensive study of the toxicity of detergents to marine life has been made. The consensus of many investigators of the Torrey Canyon oil spill was, "All that can be said is that acute effects on some animals are detectable at less than 1 ppm of detergent and that as the concentration increases, so the effects mount progressively, and extend over a wider variety of species." Another study[26] concluded that detergents are highly toxic and their use to clean up oil in areas with marine life constitutes a cure worse than the disease itself.

Based on the results of many studies of a number of different oil spills, it can be concluded that extensive use of detergents in a confined area such as a harbor would produce a very high mortality of the marine fauna in the harbor and contiguous tidal area. Relatively little damage to the marine flora could be expected and almost no damage would occur to property.

A number of proprietary, particulate materials are marketed which will, it is claimed, cause the oil to sink. The oil adheres to the particles and many of the resulting oil-coated particles agglomerate. The resulting mass then sinks. The oil and sinking agent are supposed to set to a solid mass and completely immobilize the oil. However, none of the materials tested during one investigation retained the sunken oil permanently.[27] It was also concluded that other, cheaper materials such as sand, brick dust, crushed clinker, and Portland cement were just as effective in sinking the oil as were the proprietary materials. Another study concluded that the use of sinking agents is to be recommended only in deep water beyond normal fishing grounds, i.e. off the continental shelf.[28]

It is concluded that the use of sinking agents to combat an oil spill in a harbor would be of only temporary benefit. Experience indicates also that the effectiveness of their use in sinking the oil would be questionable with the extremely viscous Bunker C as well as with Navy Special Fuel Oil. They might work well in removing JP-5 or Distillate Fuel from the surface. However, experience shows that oil, sunk to the bottom with the aid of sinking agents, will resurface gradually. The resurfaced oil will be well weathered and less objectionable and, when it resurfaces, it will have to be disposed of. Sinking the oil would

greatly prolong one of the harmful aspects of an oil spill. The length of time that the edible marine fauna could be contaminated would be greatly extended.

REFERENCE PORTS AND HARBORS

Selection of Reference Ports and Harbors

The representative domestic ports and harbors accessible to U.S. Naval vessels can be divided into two broad categories--those located on large bodies of water, such as Puget Sound, Narragansett Bay, and San Francisco Bay, and those located on relatively small bodies of water. The more distinct differences relative to oil pollution and oil pollution control between these two categories are a) greater potential for larger wave height generation on the larger bodies of water and b) greater utilization for recreation and sport and commercial fisheries on the larger bodies of water. With few exceptions, all of the Naval facilities located on both large and small bodies of water are relatively near both commercial and industrial wharves and small craft marinas. All of these facilities are subject to the effects of tidal action with rather broad ranges of tidal flushing and diffusion coefficients. Water depth for passage of deep draft vessels to berthing areas of almost all harbors is maintained by dredging at depths averaging less than fifty feet. In many cases, these channels influence the current patterns associated with tidal movement. At each Naval facility, local winds and surface currents are the predominate factors governing migration of spilled oil which can, in almost all cases, come in contact with commercial facilities. Many of the bodies of water on which these facilities are located are connected to large estuarine areas which support an abundant variety of migratory and water fowl. Long term exposure of most of the harbor areas to pollution from both municipal and industrial pollutants has already significantly affected commercial shellfish grounds and pelagic fish populations. This effect is less pronounced in the larger bodies of water with the exception of San Francisco Bay, which is relatively shallow and has a high concentration of industrial facilities on its shoreline. The time required for the complete flushing of bay and harbors is widely varied. Typically, San Diego Bay which has a median volume of 78×10^9 gal undergoes a complete flushing approximately every ten days and has a half life for any dispersed material in the bay of about seven days.[29] All of the bays and harbors on which Naval facilities are located are open to access by civil as well as naval vessels and the variety of these vessels and the frequency of their movement is widely varied. With few exceptions, the consequences of oil spillage in bays and harbors frequented by U. S. Naval vessels would be deleterious and jeopardize recreational resources, aquatic life, and both public and private property.

Detailed information obtained during the course of this study on the geographic, physical, meteorologic, hydrographic, and resource features of United States ports and harbors is given in Appendix A.

Table 3 summarizes pertinent physical, environmental, and resource data for domestic ports and harbors having the greatest Naval ship traffic and the greatest propensity for petroleum product spillage. These are the sites selected as reference installations for the determination of parameters in connection with the effectiveness studies, and for the assessment of resources vulnerable to damage by petroleum product spillage.

Oil Pollution Regulations And Enforcement

The level of acceptable water quality may vary rather widely as a function of its useage. Most states recognizing this have now adopted standards for use in the 1970's. These standards are now being reviewed by the Department of Interior.

Many of the coastal states have already adopted water quality standards for navigable streams and coastal waters and these standards are regulated by state law.

Enforcement against pollution of interstate or navigable waters is supported by several federal efforts, the most significant of which are: Executive Order 11288 which deals with prevention, control and abatement of water pollution by federal activities, the Water Quality Act of 1965 and the Oil Pollution Act of 1924 as amended. The latter places the responsibility for the discharge of oil from a boat or vessel on the person discharging or permitting the discharge of oil from that boat or vessel. (Person means any individual, company, partnership, corporation, association, owner or employee of a vessel.) Said person is responsible for the removal or expense of removal of the discharged oil subject to a fine of $2500 and/or imprisonment not to exceed one year. The vessel, if other than one owned or operated by the United States, is liable for a penalty not to exceed $10,000. The limit of liability for this responsibility may be significantly increased in the future.

Two new legislative bills have been introduced, S-7 to the Senate and H.R.4148 to the House of Representatives. H.R.4148, if passed, would increase the assessment of any owner or operator of any vessel which willfully or negligently discharges oil to $10,000 for each offense. The owner or operator of the vessel would be responsible for the removal of the oil or liable to the extent of $10,000,000 or $100 per gross registered ton of such

TABLE 3. Data Summary--Reference Ports and Harbors

Physical Characteristics				Environmental Characteristics			Resources				
Port or Harbor	Area (Mi^2)	Ave. Depth (Ft)	Shoreline (Mi)	Maximum Current (Knots)	Mean Sea Temp (°F)	Expected Wave Height--90% of Time (Ft)	Recreational Beaches	Boat Marinas	Sport Fishery	Commercial Fishery	Commercial Shellfish
Massachusetts Bay	187	35	95	1.0	50.3	0.77	Yes	Yes	Yes	No	--
Narragansett Bay	84	35	110	1.1	51.8	1.19	Yes	Yes	Yes	No	Yes
Delaware Bay	576	40	204	2.4	57.4	1.09	Yes	Yes	Yes	No	--
Charleston Harbor	17	38	58	2.0	68.0	0.59	Yes	Yes	--	--	--
Jacksonville	24	34	96	1.0	73.6	--	Yes	Yes	Yes	No	--
San Juan	--	--	--	1.0	81.0	0.69	Yes	Yes	Yes	--	--
Puget Sound	767	80	1157	5.0	50	1.4	Yes	Yes	Yes	No	Yes
San Francisco Bay	309	40	160	3.1	55.6	1.63	No	Yes	Yes	No	No
San Pedro Bay	13.8	42	15	1.0	61.8	0.39	Yes	Yes	Yes	No	No
San Diego Bay	14	30	28	3.0	61.4	0.6	Yes	Yes	Yes	No	No
Pearl Harbor	8	40	33	0.5	78.1	1.36	Yes	Yes	Yes	--	No

offending vessel, whichever is the lesser amount, if the United States removes the oil. The responsibility for oil discharges by an onshore or offshore facility is similar except that the limit of liability would be $8,000,000.

This, of course, briefly describes only a portion of the proposed legislation but indicates the level of future possible liabilities.

Enforcement of state and local statutes and ordinances is also possible. With few exceptions, such as the states of California and Rhode Island, there are no coastal states with regulations regarding the use of chemicals for the removal of discharged oil from the shorelines and coastal waters. Most of the decisions related to this subject are made on an ad hoc basis. In California's case, water pollution control is implemented with the California Fish and Game Code Section 5650 which reads:

> "Water Pollution: Prohibitions and Restrictions. It is unlawful to deposit in, permit to pass into, or place where it can pass into the waters of this state any of the following:
>
> (a) Any petroleum, acid, coal or oil tar, lamp-black, aniline, asphalt, bituminus or residual product of petroleum or carbonaceous material or substance.
>
> (b) Any sawdust, shavings, slabs or edgings.
>
> (c) Any factory refuse, line, or slag.
>
> (d) Any cocculus indicus.
>
> (f) Any substance or material deleterious to fish, plant life or bird life."

Section 1201.0 of the California Fish and Game Code makes the violation of Section 5650 of that code a misdemeanor.

The state of Rhode Island Department of Health adopted a strict set of oil pollution controls rules and regulations in 1957, which specify the requirements and procedures for the handling of oil and the transfer of oil to and from marine vessels. It has since been unlawful for any person to discharge or cause, suffer, or procure to be discharged, or cause or suffer to escape any oil into any waters of the state on penalty of a fine of not more than $500, or by imprisonment for not more than one year, or both fine and imprisonment.

Although many regulations regarding the pollution of coastal waters are in force, it can be said with some assurance that more and tighter controls are forthcoming.

EFFECTIVENESS ANALYSIS

Systematic analysis of the effectiveness of systems for removal of petroleum product spills from port and harbor water surfaces requires assessment of specific operational aspects under a range of conditions. These conditions are parameters whose extremes are the boundaries for the assessment.

"Effectiveness" is not quantifiable unless specific characteristics which contribute to or detract from the overall effectiveness are considered. The identification of such characteristics, criteria for judging them, and a rational plan for combining them into overall effectiveness are presented in the following paragraphs.

Effectiveness Criteria

The criteria for the effectiveness measurement should minimize the subjective judgment which must be employed. Rather than attempt to finely rank each system with respect to the criteria, which would inject undesirable subjective judgment into the analysis, we have chosen to establish the individual criteria in terms of minimal performance requirements. Each system is then given a numerical index which reflects whether it exceeds, meets, or fails to meet each of the criteria. The sum of these indices, for all combinations of parameters, then reflects the overall relative effectiveness of a particular system.

The effectiveness criteria employed in this study are listed in Table 4. The rationale for their development is given in succeeding paragraphs.

TABLE 4. Effectiveness Criteria

Operational Aspect	Criteria
Completeness of Removal	Essentially complete removal in consideration of environmental, geographic, and hydrographic parameters.
Speed of Application	Recovery at a rate such that removal from surface waters is complete before a slick causes damage or before it spreads so thin that it cannot be effectively treated. Includes deployability and mobility considerations.

TABLE 4. (contd)

Operational Aspect	Criteria
Does Not Increase Pollution or Hazard	Must not introduce materials having greater propensity for property or recreational resource damage than the contaminating petroleum product. Primarily applicable to chemical or chemomechanical methods.
Applicability to Limited Access Areas	Must be capable of operation among piers, berthed ships, pilings, and structures which limit access. Primarily applicable to spills in berthing areas. Judgment based on maneuverability and size.
Sensitivity to Natural Phenomena or Floating Debris	Must be capable of operating under the anticipated sea, wind and current conditions prevailing at spill scenes 90% of the time. Must not be rendered inoperable by minor floating debris or, where applicable, by water-in-oil emulsions. Primarily applicable to open area spills.
Toxicity to Marine Life	Will not contaminate fisheries and other commercially or recreationally significant marine life to cause mortality, condemnation of fish products, or flavor degradation.
Availability	Will be available for application at least 95% of the time in consideration of reliability and repairability of candidate systems.

Completeness of Oil Removal

One of the important performance characteristics of a petroleum product spill removal system is the degree to which it can

approach complete removal of the petroleum product from the water surface. Systems which are less than perfect may be adequate if the fraction removed is sufficient to effectively mitigate the effects of the spill--property damage, destruction of marine life, and damage to recreational resources. This would be the case if the residual material remaining on the surface can be harmlessly removed by natural mechanisms. Also, it requires that chemically dispersed materials do not reappear at the surface at a later time.

Among the factors which relate to the degree of completeness required of a spill countermeasure are:

- Potential property damage due to residual material--depends on characteristic of petroleum product
- Potential damage to marine life due to residual--depends on characteristics of petroleum product
- Size of spill
- Frequency of spillage
- Winds and currents at spill locale

This study is concerned with relatively small spills of specific petroleum derivatives--Bunker C, Navy Special, JP-5, and Distillate Fuel.

Information on rates of natural degradation (bacterial action, oxidation, and dissolution) is limited to certain crude oils and to very specific environmental conditions. It is not possible to extrapolate these data to the diverse parameters of concern in this study.

In reality, any system worthy of consideration must be theoretically capable of essentially completely removing the offending product from the water surface. Some systems, especially mechanical ones, cannot be expected to do this under certain adverse combinations of environmental, geographic, or hydrographic parameters considered in this study.

Each system will be evaluated for the combinations of parameters involved in this study, by considering its design features which detract from or contribute to the completeness of petroleum product removal. Those which are capable of providing essentially complete removal will be given an index of (+1) and those which have severe limitations in this regard will be given an index of (-1). Those which appear theoretically capable of complete removal performance, but are undemonstrated for the particular combination of parameters involved, will be given an index of (0).

Speed of Application

A measure of the effectiveness of an oil spill countermeasure is its ability to contain or remove the offending material before it damages vulnerable property or marine life. Oily materials generally spread, or decrease in thickness, with time after spillage, and removal must also be effected before a slick becomes so thin that it is untreatable or unrecoverable.

Where the wind conditions are calm and currents are not significant, the rate of movement of the edge of a slick will be controlled by the spreading rate. No directly applicable quantitative data on spreading rates for the materials of concern (JP-5, Navy Special, Bunker C, and Distillate Fuel) have been found. However, the previously cited work of Blokker and Berridge, et al,[1,2,] provides some basis for estimation of rates of oil slick spreading. Calculated slick characteristics based on these works are shown on Table 5. The Blokker equation can be stated as

$$D^3 = \frac{24}{\pi} K(d_w - d_o) \frac{d_o}{d_w} V_o t + D_o^3$$

where D = slick diameter, meters

d_w, d_o = density of water and oil, respectively

V_o = volume of oil, cubic meters

t = time after spillage, minutes

D_o = slick diameter at $t = 0$

K = a constant depending on the oil

In these calculations, the density of sea water was assumed to be 1.02 g/cm^3 and the petroleum product density was taken from Table 1. Since the driving force for spreading is proportional to the difference in density between the water and oil, and the density of Bunker C can be greater than that of sea water, the Bunker C will have little or no tendency to spread. In addition, the pour point of Bunker C will usually be above the temperature of the sea water. This will further inhibit spreading.

Values of K for the petroleum products of interest in this study have not been determined. However, Blokker has determined this constant for several refined products, some of which resemble JP-5, Navy Special, and Distillate Fuel. The JP-5 and Distillate Fuel have similar densities and viscosities and closely correspond to Blokker's gas oil (Sp. Gr. = 0.83, μ = 4.3 cP at 20 °C). Navy Special is similar to the lubricating oil tested (Sp. Gr. = 0.90, μ = 490 cP at 20 °C). The values of K, for these materials, were 15,000 min^{-1} and 9800 min^{-1},

TABLE 5. Theoretical Slick Dimensions After Spill

$$(\text{Diameter of Slick})^3 = \frac{24}{\pi} K(d_w - d_o) \frac{d_o}{d_w} V_o t + D_o^3$$

	Time After Spill	200 Gallon Spill: Thickness, in.	200 Gallon Spill: Area Thousands of ft^2	2,000 Gallon Spill: Thickness, in.	2,000 Gallon Spill: Area, Thousands of ft^2
	10 min	0.0562	6.4	0.113	28.4
Navy	1 hr	0.0155	20.7	0.034	94.7
Special	2 hr	0.0099	32.5	0.022	149.5
	5 hr	0.0054	59.5	0.012	277.0
	10 hr	0.0039	94.7	0.0073	439.0
	10 min	0.0135	23.7	0.0293	109.8
JP-5 and	1 hr	0.0041	77.9	0.0089	362.0
Distillate	2 hr	0.0026	123.7	0.0057	576.0
Fuel	5 hr	0.0014	227.0	0.0030	1,060.0
	10 hr	0.0009	362.0	0.0019	1,682.0

respectively, and were used herein. It should be noted that the K value is remarkably insensitive to viscosity. Furthermore, since the thickness of an oil slick at a given time is proportional to $K^{-2/3}$, a K which was 50% too large would result in only a 24% error in the calculated thickness. An 11% change in the specific gravity of the oil from 0.90 to 0.80 and other things being equal, would give a corresponding change of 45% in the slick thickness at a given time. Density is a very important factor in the rate of spreading.

There are two other factors concerning the rate of spreading of an oil slick which are pertinent to this study. The first is that the initial rate of spreading, immediately following the failure of the oil container, is assumed analogous to the sudden failure of a dam. The potential energy of a thick oil layer is essentially converted into kinetic energy and the effects of viscosity, evaporation, surface tension, and interfacial tension are negligible during this first phase. Blokker found that this first phase continued until the slick thickness had reduced to about 2 cm. From this point on, he found that 90% or more of the potential energy was dissipated in overcoming friction. The first phase requires on the order of one minute for a 100 m^3 (26,400 gal) spill. Thus the area covered by a spill of 200 gal would equal 407 ft^2 in less than one minute, and by a 2000 gal spill, 4070 ft^2. After the oil slick had reduced to this thickness, the Blokker relationship would apply and the rate of spreading for JP-5, Distillate Fuel, or Navy Special can be estimated from the ranges of values given in Table 5.

The second factor of importance is that, as shown by Berridge, the thickness of a slick, after the lapse of a full day, tends to approach the same value (0.0008 to 0.0012 in. in their reported tests) for a group of oils covering a wide range of properties. It is probable that the JP-5, Distillate Fuel, and Navy Special would all exhibit this characteristic.

At some point in time, the effects which compete with the spreading force will become controlling. These are evaporation with the attendant density and viscosity changes, and the formation of water-in-oil emulsions. Evaporation, particularly, can become a very important factor for products having high vapor pressure constituents. Blokker found that up to 80% of a gasoline slick evaporated in three hours under moderate wind conditions. In the cases of interest in this study, evaporation is less important--but still causes the theoretical slick dimensions to be conservatively large.

Under ideal conditions, with surface active components, films on the order of 4×10^{-5} inch thick have been observed to

form after 40 to 100 hr. Blokker also found, however, a final film thickness of 150 microns for gas oil on uncontaminated water. This material is most representative of the materials considered in this study, and this thickness is a reasonable minimum film thickness for effective operation of most mechanical removal systems.

The required recovery rate, within the previous context, revolves about the ability of a system to treat a given water surface area within a specified time span. Effectiveness criterion is best expressed for rapidly spreading materials as area treated per unit time. For slowly spreading materials such as Bunker C, the required recovery rate is best expressed as volume treated per unit time.

It is apparent that the required treatment rate will be a function of the characteristics of the oil derivative involved, the size of spill, the location of spill, and the type of recovery system involved.

The material requiring most rapid treatment, on the basis of spread rates, is JP-5, followed by Distillate Fuel, Navy Special, and Bunker C, in that order. For Bunker C, where little or no spreading tendency exists, the required treatment rate would be governed by other factors such as the need for operation during daylight hours or the need for recovery before winds or currents carry the material to vulnerable property or marine life.

For all treatment methods, deployment speed becomes an important consideration for rapidly spreading oil slicks.

Criteria for all methods whose removal efficiencies are not sensitive to film thickness may be governed by the ability to visually locate a spill slick. For spills close to docks, sufficient illumination is assumed to be available for location and treatment. However, for spills in a bay or sound, effective treatment could only be undertaken during daylight hours. For such cases, it is arbitrarily assumed that at least five hours of daylight would be available for countermeasure application in the vast majority of cases.

For some postulated spill cases, onshore currents and winds may become controlling.

It follows from the above discussion that different quantitative recovery rates are required for each combination of parameters. For purposes of this study, and on the basis of the above reasoning, criteria were selected for various combinations of parameters. These are shown on Table 6.

TABLE 6. *Minimum Speed of Application Criterion for Governing Parameters*

Location of Spill (Parameter)	Petroleum Product (Parameter)	Spill Size, gal (Parameter)	Type of System (Parameter)	Minimum Treatment Rate	Basis
(1) In proximity to piers and berthing areas where access is limited by pilings, enclosed areas, floats or booms.	JP-5 and Distillate Fuel	200	Mechanical	735 ft^2/min	Minimum film thickness treatable Treatment within a fixed time span
			Chemical	735	
		2000	Mechanical	3400	
			Chemical	3400	
	Navy Special	200	Mechanical	550	
			Chemical	550	
		2000	Mechanical	2450	
			Chemical	2450	
	Bunker C	200	Mechanical	0.67 gal/min	
			Chemical	0.67	
		2000	Mechanical	6.7	
			Chemical	6.7	
(2) Readily accessible open areas of bays and sounds when environmental conditions are moderately severe; (assume wind 20 mph on shore, and spill 1-1/2 mile off-shore).	JP-5 and Distillate Fuel	200	Mechanical	790 ft^2/min	Recovery before oil reaches shore. 1/2 hr for deployment and slick movement at 4% of wind velocity assumed.
			Chemical	790	
		2000	Mechanical	3650	
			Chemical	3650	
	Navy Special	200	Mechanical	590	
			Chemical	590	
		2000	Mechanical	2700	
			Chemical	2700	
	Bunker C	200	Mechanical	2.4 gal/min	
			Chemical	2.4	
		2000	Mechanical	24	
			Chemical	24	

It should be recognized that these detailed criteria apply to systems which do not utilize booms or other containment devices to prevent free wind-driven or spreading movement of the offending material.

For purposes of comparing various systems, the following indices will be utilized in the total effectiveness:

	Index
System exceeds criteria	+1
System meets criteria	0
System fails to meet criteria	-1

Effect of Method on Pollution and Hazard

Generally, mechanical methods of spill treatment do not cause adverse effects. An exception to this would be mechanical systems which involve containment by booms or corrals when employed on spills of JP-5. If chemical dispersants were not applied to minimize the fire hazard, prevention of spreading of this flammable material, by gathering it in such containment, might be undesirable because of the associated fire hazard.

Chemical methods must be carefully considered because of the possibility that the chemical may be more harmful than the petroleum product. Chemical materials that would degrade structures, accelerate corrosion, or otherwise attack submerge cables, pipelines, or water craft are of particular concern. Also, the possibility of the dispersed material reappearing at a later time must be considered.

The index to be applied will be as follows:

Effect	Index
Reduces Pollution or Hazard	+1
No Effect on Pollution or Hazard	0
Increases Pollution or Hazard	-1

All cases based on specific combinations of parameters and for particular systems will be individually considered and indexed as indicated.

Applicability to Areas Having Limited Access

A typical port installation includes piers supported by pilings, breakwaters having irregular geometry or porous characteristics, berthed ships, and various irregular fixed or floating objects. The presence of these kinds of objects can make a countermeasure system, which is eminently satisfactory on the open water, totally ineffective.

Consideration of this aspect, in the effectiveness analysis, will consist of evaluating each component of all hypothetical and actual systems in terms of:

- Access requirements in terms of water surface area and height and width of planes perpendicular to water surface needed for effective application
- Maneuverability of system in terms of turning radius and reversability.
- Stability if floating or fixed objects are struck during movement.

Each system will be individually evaluated for the parametric situations involving the obstructions mentioned above. Indices will be assigned for each system and parametric case as follows:

Applicability to Limited Access Areas	Index
Excess Needs	+1
Meets Needs	0
Does Not Meet Needs	-1

Sensitivity to Natural Phenomena or Floating Debris

Many mechanical systems are susceptible to stalling from pluggage or blockage by floating debris. It is usual, in port installations, for variable amounts of debris such as driftwood, paper, etc. to be present on the water surface. Those systems involving suction pumps, weirs, and close tolerance impellors are examples of systems which may be adversely affected by such materials. Design features such as screens, strainers, and baffles may enable a system to effectively handle such floating debris.

Systems employing rotating drums or endless belts of sorptive material are vulnerable to damage and stalling if rigid debris with sharp corners is picked up at the water surface. This characteristic may be contrary to some manufacturers' claims, but it has been observed during field application.

The sensitivity of a hypothetical or actual system to water wave and wind conditions is a significant performance factor. While it is unlikely that spillage would be of priority concern during severe storm conditions, effective systems must be usable during conditions more severe than "flat calm." "Harbors" implies some degree of protection to ships and facilities from conditions which might prevail on the open sea. Man-made breakwaters, spits, and jettys and the natural geography provide this protection. It seems appropriate, for purposes of this study, to select conditions which would prevail during the vast majority of the time--more severe than "flat calm" but less severe than open sea storm conditions.

The section on "Reference Ports and Harbors" contains summary data on the geography and prevailing weather at selected U.S. Navy installations. Those having the greatest past spillage problem and the greatest general propensity for future incidents are Puget Sound, Long Beach, San Francisco, San Diego, Boston, Charleston, Norfolk, Newport, and Hawaii. Appendix A includes wind distribution data. These data, along with the calculated short period wave height calculated from fetch and water depth, based on the method of Bretschneider,[30] are given in Table 7.

As can be seen from this table, the maximum normal wave height varies from 0.6 to 1.6 ft. For purposes of this study, the maximum wave height during spill countermeasure operations will be taken as 1.6 ft.

The indices to be applied to this aspect of countermeasure effectiveness are as follows:

	Index
Not affected by 1.6 ft waves or debris	+0.5
Slightly affected by 1.6 ft waves or debris	0
Rendered inoperable by 1.6 ft waves or floating debris	-0.5

Toxicity to Marine Life

Most chemical dispersants are toxic to marine life. Toxicity thresholds range from approximately 5 ppm to 10,000 ppm for presently used commercial materials.[31] The actual effect of using a specific dispersant in a given situation is dependent on the marine life present, the diffusion characteristics at the spill locale, the effectiveness of tidal flushing, the application ratio, and the physical characteristics of the spill material. Standards regulating the use of dispersants range from "unlimited" to "none permitted." FWPCA rules employed during the Santa Barbara incident permitted chemical dispersants to be used at ≥1 mile off shore at concentrations equivalent to 5 ppm in the top three feet of water.[6]

Although the California State Fish and Wildlife Code does not permit the use of chemicals, the widespread use of such materials in the San Diego area has long been known. This particular harbor area has adequate tidal flushing and no harm due to chemical usage has thus far been reported. Studies performed at this locale show that the half life of a spilled material, due to diffusion and tidal flushing, is on the order of seven days.[32] Such data, unfortunately, are not available for other potential spill sites covered in this study.

TABLE 7. Calculated Wave Height for 90% Probability

Port Area	Maximum Wind Velocity Expected 90% of Time, mph	Prevailing Wind Direction	Fetch, mi	Average Water Depth, ft	Maximum Wave Height, ft	Average Wave Length, ft	Minimum Wave Length, ft
Puget Sound	≤18	SSW	3.0	130	1.4	24	8
Long Beach	≤9	W	0.8	45	0.4	8	3
San Francisco	≤20	WNW	5.0	60	1.6	31	11
San Diego	≤11	WNW	2.0	30	0.6	13	4
Boston	≤21	SW	0.5	35	0.8	15	5
Charleston	≤16	NE	0.8	38	0.6	12	4
Norfolk	≤18	SW	2.0	41	1.1	21	7
Hawaii	≤20	ENE	2.5	40	1.4	26	1

The FWPCA rule of 5 ppm in the top three feet of harbor water, although somewhat arbitrary, does have some logical basis. It assumes typical diffusion rates, is safely below the toxicity level for most dispersants, and assumes the dispersant is effectively mixed with the oil to provide some vertical distribution of the resulting oil-in-water emulsion. Use of this rule would permit chemical dispersant application at a rate of 9.5×10^{-4} lb/ft^2 of surface area.

The amounts of chemicals required for emulsification is generally two to three times the manufacturer's recommendation--mostly due to the variance between field application and laboratory testing. A typical chemical dispersant must be used in the ratio 1:3 for effective use. This would correspond to effective treatments of oil slicks on the order of 5×10^{-4} in. (or less) in thickness. Bunker C, because of its high density, would never be expected to spread this thinly. Navy Special would attain such a thickness on the order of 28 hours after spillage. The other materials (JP-5 and Distillate Fuel) would attain this thickness on the order of five hours after spillage. It is concluded that chemical dispersants, within the above framework, cannot be effectively used for spillage of Bunker C or Navy Special without exceeding most toxicity limits.

The indices to be applied to this criterion for system effectiveness evaluation were basically derived from the above reasoning. The applicability of chemical methods will depend on the circumstances of the specific spill situation and is exemplified for small spills as follows:

Spill Material	Spill Location	Surface Currents and Tidal Flushing	Index
JP-5	Berthing Areas	Adequate	+0.5
		Inadequate	0
	Open Water	Adequate	+0.5
		Inadequate	0
Distillate Fuel	Berthing Areas	Adequate	+0.5
		Inadequate	0
	Open Water	Adequate	+0.5
		Inadequate	0
Navy Special	All	All	0
Bunker C	All	All	0

Similar reasoning was applied to all of the various ranges of parameters durint the "total effectiveness" compilation. For example, the indices for large spills ($\leq$2000 gal) were taken as (-0.5) for all cases clearly exceeding allowable toxicity ranges.

Availability

An effective system for removal of oil pollutants from the surfaces of harbor and port waters must, of necessity, be available for use when needed. Sev ral factors influence the availability of specific systems:

- Reliability--invulnerability to failure due to malfunction or damage by external forces (such as waves, currents, and collisions)
- Maintainability--lack of dependence on special facilities or skills, ease of disassembly/assembly, and ready availability of replacement components
- Portability--ability to quickly deploy to spill scene

Many of the systems to be studied have been extensively used and corresponding historical data are available. Other systems have not been used enough to provide a sound basis for judging these aspects. In the latter instances, the systems will be analyzed on the basis of the experience with components involved, or similar components, to derive estimates of availability probability.

Systems estimated to be available 95% of the time will be given an index of +0.5, and all others will be given an index of zero.

Effectiveness Parameters

Effectiveness analysis involves assessment of each candidate system with respect to all effectiveness criteria over a range of conditions. These conditions may properly be called "parameters." They are the expected characteristics of spill incidents, the geographic and physical characteristics of spill sites, and the environmental conditions at spill sites. Representative ranges for these aspects were derived from available historical information and descriptive materials. The parameters selected for this study, and the rationale for their development, are given in the following paragraphs.

Size and Frequency of Spills

The frequency of spillage at a given site is important because very frequent spills can generate a chronic pollution situation if effective countermeasures are not routinely employed. For sites having very few spills, the cost of cleanup per gallon of spillage may be very high because of capital costs.

Navy installations servicing many diverse types of ships and involved in extensive fuel handling can be expected to have a significant incidence of spillage. The spillage can be due to casualty collision, personnel error (tank overfilling, premature hose uncoupling, etc.), and leaking tanks or piping.

The size range of spills from Navy vessels has been reported, based on a one year period, as less than 100 gal to over 2000 gal. Of the 117 spills during this period at two West Coast installations, more than half were less than 200 gal and only seven were more than 1000 gal.[33] Information drawn from other sources on 147 spills over a 15 month period at San Diego indicate that 50% of these spills were 20 to 100 gal, 40% were 100 to 500 gal and 10% were greater than 500 gal.[34] In 1966, some 67 spills from Naval vessels in the Long Beach-San Diego area were reported.[35] Communication with the Puget Sound Naval Shipyard generally confirmed these values (about 20 spills/year at an average of about 200 gal). It should be recognized that most of the above values are estimates--there is virtually no documented support which is known to have been verified by tank gauging.

For purposes of this study, incidents are classified into two representative size ranges: $\leq$200 gal and $\geq$2000 gal. These ranges are expected to encompass the vast majority of spill incidents and be representative of the extremes. Frequency of spillage was also classified in terms of extremes, $\geq$50 spills per year to $\leq$10 spills per year.

Petroleum Products

This study is concerned with the petroleum products in use by the Navy:

- JP-5 Turbine Fuel
- Navy Special Fuel Oil
- Bunker C Fuel Oil
- Distillate Fuel (new specification--expected to be used for most Navy craft sometime in the future)

Specifications and characteristics of these materials are given elsewhere in this report.

Characteristic Harbor Water Movement

Surface and tidal currents can cause dramatic variation in the effects of an oil spill. Moderate tidal currents can carry a spill slick into vulnerable areas or away from them; enhance the effectiveness of dispersants; make a slick difficult or impossible to locate; and cause mechanical containments to be totally ineffective.

For purposes of this study, representative extremes will be considered as a parameter--largely as to the effects of currents on equipment effectiveness. These, with representative examples, are:

	Examples
(1) Surface Currents and Tidal Flushing Minimal	Pearl Harbor Massachusetts Bay
(2) Surface Currents $\geq$0.5 Knot and Adequate Tidal Flushing	San Diego Puget Sound Delaware Bay

Generic Identification of Potential Systems

The treatment and/or recovery of petroleum products released to a water surface can be by one (or a combination of several) of the following methods:

- Chemical dispersion
- Sinking with sorbent materials
- Sorption or gelling
- Physical retrieval
- Burning *in situ*
- Degradation (natural or enhanced)

Some of these methods, such as chemical dispersion, do not remove the oil from the marine environment, but rather only from the water surface. Dispersal or sinking can remove a potential

fire hazard (when it exists) and minimize or eliminate many forms of damage to harbor facilities and waterfowl. However, the emulsified oil and chemical dispersants significantly increase the toxicity hazard to subsurface marine flora and fauna.

The equipment, materials, and techniques, described in the following sections, will be limited to those designed to cope with limited spills of petroleum products (i.e. up to a few thousand gallons).

Three discrete operational areas are identifiable with respect to oil spill treatment and recovery:

- Containment
- Chemical treatment and/or physical retrieval
- Disposal of the recovered product

The three operational areas are essentially sequential and employ separate equipment, materials, and techniques. The systems to be considered do not necessarily entail operations within all three areas.

Procurement and vendor information on specific products is given in Appendix B.

Containment

Employment of a barrier which confines the oil and thus prevents subsequent spreading or drifting is advantageous in almost every spill situation. The advantages of containment include:

- Limiting of pollution to the immediate area of the spill.
- Reduction of the water surface area to be cleaned.
- Possible intensification of the slick to the point that physical recovery becomes more feasible.

Perhaps the only disadvantage of containment (other than cost) is the possible creation of a fire hazard by confining petroleum products, such as JP-5, which would otherwise spread rapidly on the water surface to the point that no fire hazard existed. This potential disadvantage can be overcome by the application of chemical dispersants or other chemical agents which reduce or eliminate the fire potential of the petroleum product.

The potential rates of spread or drift of oil in a typical spill situation requires that the barrier be either in place before the release or be rapidly deployed for optimum effectiveness. The majority of spills emanate from essentially a point source over a short period of time; therefore, the perimeter required to encircle or contain a spill is a function of time following the incident. Complete encirclement is normally

required to prevent spreading. A lineal barrier is sufficient to prevent drift due to surface currents or wind. If the prevailing wind or surface current induces drift of the slick at a rate exceeding the rate of normal slick spreading, a lineal barrier with a natural catenary form across the path will accumulate the released oil until it can be recovered.

The three general areas of application for oil booms are:(36)

- For oil removal operations
- As permanent barriers
- For emergency containment

Oil removal operations can employ booms for dragging or sweeping operations as well as reducing the confinement area by gradually decreasing the perimeter. Permanent barriers, in contrast to emergency booms, should be sun, oil, fire and abrasion resistant.(37)

Physical barriers for oil retention are generally within the following classifications:

- Floating booms
- Pneumatic barriers (underwater air barriers)
- Chemical barriers

Floating booms are much more extensively employed than the other types.

Floating Booms. Floating booms are available commercially in a wide variety of sizes and configurations or can be fabricated from any number of available materials such as wooden timbers or fire hoses. A list of commercial booms is included in Appendix B.

An effective floating boom must provide a vertical barrier at the water surface, which extends several inches above and an equal or greater distance below the water surface. The barrier is commonly formed by combining a buoyant section with a rigid or weighted skirt extending downward into the water. The buoyant portion consists typically of either an inflatable bladder or buoyant material such as plastic foam, cork or wood timbers. Skirts typically consist of plastic sheet or rubberized fabric with lead weights or steel chain to provide ballast at the bottom edge.

A novel innovation for boom emplacement and adjustment, used by the Corpus Christi Refinery Terminal Fire Company, employs two propellers at one end of an inflated fire hose.(37) The propellers are remotely operated by air pressure from lines running through the boom, thus permitting emplacement by an operator on the terminal end.

Makeshift booms such as wooden timbers or inflated fire hoses generally lack skirts and, therefore, effective usage is restricted to waters that have little or no surface currents and to spill situations in which the contained oil does not reach an appreciable thickness. Skirts or extended draft are necessary in the presence of surface currents to prevent the oil from being swept under the boom as it accumulates. A floating oil slick against a barrier behaves much like an iceberg in that about 90% is below the mean elevation of the surrounding water, depending on the density of the petroleum product. Thus, accumulating oil can be rather easily swept under a boom with insufficient draft as the slick thickness increases due to wind or surface currents. A skirt is particularly necessary when a boom is to be employed for dragging or sweeping.

Flexibility and structural strength are other requisites of an effective containment boom. Flexibility permits the boom to follow the profile of the water surface. Even in the most sheltered harbor waters, the wake of boats passing in the area can wash oil over an inflexible boom. Satisfactory flexibility can normally be obtained either by employing flexible materials, such as foamed plastics, for the buoyant section or short sections (not more than a few feet long) of relatively rigid materials connected with flexible joints.

Deployment considerations require that an emergency containment boom be either capable of being towed at speeds up to about 10 knots or deployable from the deck of a vessel at the site of the incident. Floating booms with sufficient flexibility can be stored on drums from which they can be unreeled for deployment. Many commercial booms can be folded on a pallet, like an accordion, for storage.

Emergency containment booms generally require a relatively greater structural strength, especially if they are to be towed to the scene. Permanent booms can be moored in place to minimize environmentally induced forces, but emergency containment booms often must be positioned and held with ships which can induce significantly greater structural forces.

Floating booms employing air-filled chambers for buoyancy, although relatively less expensive than other types, are not recommended for emergency situations because of susceptibility to puncturing and subsequent sinking. This type of boom can, however, be satisfactorily employed as permanent booms such as around ships or other areas susceptible to spills.

Pneumatic Barriers. Pneumatic barriers (underwater barriers) can provide a sufficient surface current to contain oil spills in harbor waters if winds and surface currents are not excessive. The operation entails injection of air through a perforated hose or pipe into a water column. The water section into which the air is injected is reduced in density with respect to the surrounding water, and a resultant upwelling occurs. The vertical motion of the water produces a "mound" on the surface which results in a surface current flow from the point of air emergence. Water is drawn from the region immediately above the submerged pipe thus producing a circulation. Surface currents up to five ft/sec can be produced with large compressors injecting up to 90 SCFM of air per foot of length.[38] Standard air compressors (nominally 100 psi) are generally used to provide air to the perforated hose or pipe. The advantages of pneumatic barriers include:

- Unrestricted passage of ships across the barrier.
- Relative immunity to environmental forces.
- Invulnerable to and able to contain fire on the water surface.
- In certain instances, such as when the barrier is biased across the direction of water flow, the oil can be guided to a single location to facilitate pickup.

Disadvantages of pneumatic barriers include:

- Relatively high procurement and operational costs.
- Possible slight penetration of accumulated oil as ships pass across the barrier.
- Complete negation of the effectiveness in the event of power, compressor, or pipe failure.

Pneumatic barriers must essentially be custom designed for each particular application. They have therefore been permanently installed rather than used as portable emergency containment devices. Such factors as type of oil, amount of debris present, tidal velocity, depth of water, orientation with prevailing currents and wind are important considerations in the design of the barriers. If the average current velocity of water rises above 1 to 1.3 ft/sec., the air bubbles are deflected and dispersed so that they can no longer form "mounds" of water, and the barrier loses its effect.[39] In general, efficiency of the barrier improves in proportion to water depth--shallow water requires greater volumes of air.[39]

The pneumatic barrier emplaced across the entrance to the Santa Barbara harbor following the blowout in the channel in 1969 was about 700 feet long and employed a 600 SCFM standard compressor (100 psi) on one end and a 250 SCFM compressor on the other.[6] An auxiliary floating boom was required in in shallow water areas up to a few feet deep.

Operational difficulties due to change in head have been experienced when these units are emplaced directly on a harbor bottom of relatively uneven contour. It is preferable to install the perforated pipe or hose level a short distance above the bottom; this also prevents clogging or filling with sand or mud when the unit is turned off. Flapper valves may be necessary over the holes in the pipe when sand and other particulate matter are present in the water.

Sixteen European marine terminals are using pneumatic barriers to contain oil spills. They include four major deep-water terminals, Lavera and LeHavre, France; Antwerp, Belgium; and Livorns, Italy.(40) Similar installations exist in Hamburg, Germany; Tobruk, Lybia; and Algeria.(39) The pneumatic barriers can be combined with conventional floating booms to seal off either individual ship berths or portions of the harbor. The pneumatic barrier serves as a gate to permit unimpeded ship traffic, while the less expensive floating booms seal off the remainder of the perimeter.

Chemical Barriers. Chemical barriers can be formed with such agents as a fatty acid spread at the periphery of a spill.(41) The spreading force of the fatty material will repel the nonpolar petroleum oil and push it into a smaller area. Hydrophobic (lacking an affinity for water) hydrocarbons generally do not spread well on water and can also be used for this purpose. Chemical gelling agents, if spread on the edges of a slick, in effect form a chemical barrier.

Chemical barriers are not widely employed because of extreme sensitivity to environmental factors, possible toxicity to marine life, and operational considerations such as deployment and recovery problems. Effective use of this method would be restricted to incidents where calm conditions and no currents were present.

Chemomechanical Treatment

The ultimate fate of petroleum products spilled on the water surface and either dispersed into the water or allowed to spread into a thin film is evaporation, oxidation, or biological degradation. Biological degradation, although inherently slow, is nevertheless important because the accumulation from chronic spills of persistent products, such as Bunker C, Navy Special, and Distillate Fuel, would eventually constitute a severe pollution hazard. There is little or no application in harbor spill cleanup for cultures which enhance the natural biological process, such as those employed in the "bug ponds" of the refining industry.(42) However, chemical agents used to treat oil slicks should in no way retard or stop this natural

process. Many manufacturers claim that chemical dispersion speeds up the natural degradation process; however, little or no quantitative field data is available to support these claims.

Burning of the oil on the water surface is possible if recently developed chemical "wicking" agents are spread over the slick. Although this method is attractive economically, it has no application in congested harbor areas. The resultant air pollution is also very objectionable. The only potential application areas are in open water spills when more satisfactory treatment means are not available or, perhaps, in fresh water lakes or rivers where the application of chemical dispersants is not possible because of contamination of insufficient water movement and mechanical recovery equipment is not available.

Sinking with Sorbent Materials. Several materials are employed to sorb and subsequently sink oil from slicks on the water surface. Carbonized sand has been employed extensively by the Navy, particularly aboard ships, for this purpose. Carbonized sand is manufactured by mixing beach sand and creosote and subsequently heating the coated sand to approximately 800 °F in a furnace from which air has been excluded.[43] The resultant product has an affinity for oil and repels water. Sinking agents can be efficiently employed on thick or weathered oil slicks; it is doubtful that sinkants are effective on thin films and light crudes.[44] There are three principal disadvantages to the employment of carbonized sand and other sinking agents for the removal of petroleum products from the water surface in ports and harbors:[44,45] (a) turbulence or agitation caused by storm conditions or ships passing above tends to release the absorbed oil, (b) fish, shellfish or plant life existing in the area of carbonized sand application are usually covered and destroyed by the sinking oil and sand, and (c) transporting and proper application of the sinking agent are difficult. Other sinking agents, which have been employed, include:

Sand	Vermiculite
Brick dust	Crushed stone
Fly ash	Slaked lime
China clay	"Stucco"
"Omya" clay	Coal dust
Volcanic ash	Chalk
Silicone mixtures	

The application of sinking agents in port and harbor areas is not recommended unless the prevention of an immediate fire hazard is required and other more satisfactory means are not available.

Sorption and Gelling Agents. Floating sorbent materials include a great number of different natural and synthetic materials which have an affinity for petroleum products and do not have an affinity for water. Sorbents are normally employed as part of a recovery system to prevent slick spreading and facilitate recovery of the petroleum product.

The straw from wheat stalks is the most extensively used sorbent because of its low cost and almost universal availability. The amount absorbed varies with the type of petroleum product but is reportedly 4-5 times its own weight for typical crude oils. Another source reports that straw will absorb between 8 and 30 times its weight of oil.(46) Straw would be the most effective on Navy Special and Distillate Fuel and least effective on Bunker C and JP-5. A list of commercial sorbents and other materials used for oil spill treatment is included in Appendix B.

One type of sorbent which holds great potential promise, if means can be developed to effectively recover and dispose of the agglomerated mixture, are high molecular weight polymers such as polyurethane, polyethylene, polystyrene, and polypropylene. These materials would normally be applied as a soft foam from which the petroleum product could be recovered by squeezing. Polyurethane can theoretically absorb 90% of its own volume and 100 times its own weight of oil, although difficulties have been experienced with absorbing heavy and weathered oils.(44) Small scale comparative tests of several soft foams of high molecular weight polymers indicated that polyurethane was superior, followed by polypropylene and nylon.(47) Chemical treatment with additives such as silicone can enhance the oil absorbing characteristics of these polymers.

Most floating sorbents require mixing or agitation with the oil on the water surface to achieve optimum effectiveness. Little or no toxicity to marine life results from the employment of most sorbent materials.

Gelling agents are used to congeal oil slicks by spraying the product directly on the oil. The method is relatively expensive with presently utilized products because the application ratio is, at best, one to one. The congealed mixture also can complicate recovery with many present mechanical devices because the oil is thickened considerably and thus less susceptible to pumping or gravity flow.

Chemical Dispersants

Oil dispersion with chemical emulsifiers is the most popular method of oil spill cleanup presently in use by the

Navy.[45] Hundreds of commercial dispersants are available for oil spill cleanup and a representative compilation of some of the more common dispersants appears in Appendix B. The function of these agents is to disperse the oil into a stable oil-in-water emulsion which will eventually degrade naturally in the body of water.

The majority of dispersants contain three constituents; surfactants, solvents and stabilizers. A typical dispersant is about 70-80% solvent, 10-15% surfactant, and 10-15% stabilizer. Compositions of some of the dispersants used for cleanup following the Torrey Canyon stranding include:[48]

Detergent No. 1:	66% solvent containing 24% aromatics, remainder cetyl phenyl ethylene oxide condensate
Detergent No. 2:	70% solvent containing 43% aromatics 15% tall oil
Detergent No. 3:	75% solvent containing 76% aromatics 25% mixture of ethylene oxide condensate and calcium petroleum sulphonate
Detergent No. 4:	85% kerosene extract with a high proportion of aromatics 12% nonyl phenol ethylene oxide 3% coconut diethanolamide
Detergent No. 5:	75% solvent containing 83% aromatics 7.5% tall oil 2.5% triethanolamine 10% dodecyl benzyl sulphonate as the ammonium salt 5% non-ionic detergent.

The surfactants are generally non-ionic compounds such as polyethanoxys or polyglycols. The surfactants used for oil dispersion, unlike those employed in household detergents, are "hard"; that is, they are not readily destroyed by micro-organisms.[47] The surfactants effectively alter the surface tension and cohesive properties of the oil such that the oil tends to spread and form a colloidal suspension or emulsion.

Stabilizers are employed to preserve the emulsion and thus inhibit recoalescence. Solvents allow the surfactant to penetrate into the slick and mix with the oil. Two general classes of solvents are employed: petroleum base and water base. Kerosene is a common solvent. Petroleum based and chlorinated hydrocarbons are quite toxic and the use of dispersants containing these solvents is not recommended by the Federal Water Pollution Control Administration.

The dispersion of an oil slick by emulsification or complexing reportedly permits a more rapid natural degradation because the surface area is greatly increased. However, this may or may not be true, depending on the constituents of the particular dispersant; some may inhibit biodegradation. Observations concerning the stability of the emulsions formed vary greatly, depending on the source and nature of the experiment. It is safe to assume that no emulsion formed will remain suspended indefinitely in a body of water and that the oil will eventually recoalesce on the surface in the absence of continued agitation or tidal flushing.

The amount of oil emulsified with a given amount of dispersant varies widely among products. Manufacturers' claims generally report from 5-100 parts of oil per part of dispersant. The amount dispersed varies with the type of oil treated, nature of application, slick thickness, temperature, and environmental factors. However, a reasonable assumption for typical spills in ports and harbors is that about one part dispersant is required to disperse five parts of oil.

Work done by the Naval Civil Engineering Laboratory[32] and Ontario Water Resources Commission[31] indicates considerable variation in the effectiveness and toxicity of the various products tested. Further testing of additional properties of a greater number of products is clearly needed. MIL-S-22864 (SHIPS), dated November 1, 1966, delineates a laboratory test to check the efficiency of chemical dispersants.

Quantitative information concerning the toxicity of chemical dispersants and emulsified oil to marine life under field conditions is difficult, if not impossible, to obtain for the conceivable range of marine life and conditions. Toxicity data for dispersants is of relatively little operational value unless information pertaining to the application ratios for a range of petroleum products is also available. In general, the majority of dispersants seem to be toxic to fish at concentrations of 5 to 10 ppm, although some are non-toxic at concentrations as high as 10,000 ppm.[44] Chemical dispersants have a relatively high biochemical oxygen demand. One gallon of demulsifier has the same adverse effect on the oxygen balance of water as about 2500 gallons of crude sewage.[45]

Federal Water Pollution Control Administration policy regarding the use of chemical dispersants states that they should not be used whenever the protection of (a) fresh water supply sources, (b) major shellfish or fin fish nurseries, harvesting grounds or passage areas, or (c) beaches is a prime concern. Examples of areas and circumstances where the use of such

chemicals might be acceptable include: (a) where fire or safety hazards exist, (b) where large numbers of waterfowl may perish because of the proximity of floating oil, and (c) for "polishing" or final cleanup of light slicks of oil following mechanical removal.

An almost unanimous opinion exists that chemical dispersants should not be employed for cleanup of sandy or shingle beaches. Sand can turn to "quicksand" and the oil is driven deeper below the beach surface. Beach erosion is also facilitated because of the lubricating qualities of the dispersed oil.

Physical Retrieval

The physical recovery of oil or agglomerated mixtures of oil and sorbents can be achieved either manually or with mechanized equipment designed for the recovery of petroleum or similar contaminants. Equipment for the effective recovery of agglomerations of oil and sorbents, such as straw, is currently primitive or nonexistant. More efficient devices are expected to become available in the near future. Petroleum products recovered by physical methods require subsequent disposal and the employment of sorbents can complicate existing disposal techniques and normally prevent utilization of the recovered product for such purposes as fuel. Physical retrieval includes such techniques as:

- Manual labor using crude implements
- Skimming with a suction device
- Rotating drums or endless belt devices
- Skimming with a weir

A list of commercial equipment available and other devices employed for the mechanical recovery of petroleum products appears in Appendix B.

Manual Labor. Several port and harbor areas such as Long Beach employ manual labor to recover limited spills. This technique necessitates the application of sorbents or gelling agents in most instances to enable recovery. Straw is normally spread on the slick and mixed with the oil. Retrieval is then made using crude hand implements such as pitchforks or pieces of expanded metal with wooden handles. The process is extremely slow and relatively expensive as compared to chemical and mechanical recovery. This is particularly true in locations requiring the cleanup of relatively large or numerous spills.

Suction Devices. Petroleum products can be either lifted or skimmed from the water surface with a variety of vacuum or suction devices. The general class of devices is only effective on relatively thick slicks. Most require partial or total

immersion of the nozzle in the oil. A considerable amount of water may be recovered with the oil and, therefore, the systems often employ gravity separation or decanting tanks. The tank trucks and suction pumps commonly employed to empty septic tanks can be readily adapted for oil slick removal.

Suction or siphon nozzle devices are generally portable and capable of operation in limited access spaces because the inlet nozzle can be located up to 50 to 100 feet from the pump; the pump and storage tank are often mounted on a dock or the deck of a ship while the nozzle is located on the end of a flexible hose. When properly operated on certain types of products, such as Navy Special or Distillate Fuel, the cohesive properties of the oil should cause the remaining oil to be drawn in from the surrounding area as it is recovered from a central location. Such behavior, however, could be expected only under ideal conditions on the water surface and with a relatively thick oil slick.

Heavier oils such as Bunker C and debris tend to clog intake lines and render suction devices inoperable. Another operational difficulty that can be encountered, depending on the type of pump used and whether or not the oil passes through the pump, is that of emulsification of the oil. A water-in-oil emulsion can be formed, particularly with centrifugal pumps, that is most difficult to remove from the storage tanks.

One type of suction device that recovers a high proportion of oil (assuming ideal conditions) is an air lift system. The system utilizes the principal that a high velocity stream of air moving over the surface of a slick and into a suction nozzle will entrain the oil from the surface. A bell-mouth nozzle is suspended approximately one inch above the water surface. The nozzle or ejector employs the high flow/low vacuum characteristics of a Coanda nozzle.

A pump for oil recovery recently announced by the Reynolds Metals Company uses a combination of gravity and acceleration,[49] partial pressure and vortex axial flow. The mixture entering the pump will form a vortex in which the oil remains in the center of the stream. A tube inserted in the center (forming an annulus) will draw off the oil while the sea water passes outside the tube. An 8 inch diameter pump will take in 2500 gal/min. Therefore, a 10% mixture of oil to water would be recovered at a rate of 250 gal/min. The units will be available in approximately one year.

<u>Rotating Drums and Endless Belts</u>. Numerous devices that employ some configuration of rotating drum or endless belt are either currently available or being developed. The oil is

removed from the water surface either by natural adherence to the advancing surface of the belt or drum. The oil that adheres to the bare rotating surfaces can be subsequently scraped off by a blade. Units employing hydrophobic plastic foam socks require squeezing by rollers to recover the oil. Another type of unit akin to an endless belt system employs long rolls of sorbent material, such as felt, which sorbs the oil and stores it for subsequent disposal.

Most oil recovery devices of the rotating drum or endless belt varieties, presently employed in harbors, have oil recovery capacities ranging between 200 and 2000 gal/hr under ideal conditions. One rather unique configuration presently being developed by the Royal Shell Dutch laboratories employs a large loop of sorbent material such as polypropylene "wool" which is squeezed by wringers mounted on a ship or ashore.(50)

The rotating drums and endless belt devices are generally ineffective in wave heights exceeding about six inches because the oil must come in contact with dry surfaces for effective removal and waves often cause wetting of the surfaces before contact with the oil. The proportion of oil to water recovered generally exceeds 90% when water surface conditions are not excessive. These units are most effective when advancing at very low speeds. Present units are generally not maneuverable and incapable of recovery in limited access areas. One recently developed device employs two counter-rotating drums.(51) One is rotated at a relatively high speed in the direction of water flow. A shallow immersion depth on this drum makes it effective for removing heavy, weathered oils. This drum may have a polyethylene surface which comes in contact with the oil in a dry condition and thus becomes oil-wetted. The other drum rotates slowly opposite to the water flow direction and is immersed relatively deep. The drum has a water-wetted steel surface which is more effective on lighter, less viscous oils.

Design parameters and considerations associated with rotating drums, include:(37)

1. "The theoretical retrieval rate of rotary oil cylinders is one gpm per linear foot of cylinder length when rpm has been adjusted for viscosity."
2. "Oil is not lifted from the water, but rather carried under and through before recovery on the upswing, i.e. the cylinder rotation moves the contacting surface into the water rather than out of it."
3. "Machine designs should provide positive means for control of trim, stability and depth of cylinder immersion."

4. "Cylinder rotation should be controllable to obtain high rpm for light oils and lower rpm for heavy oils."
5. "Integral oil discharge pumps should be positive displacement, rotary units of the progressing cavity type, to handle sludges, small solids, and the range of viscosities commonly encountered in oil skimmer services."

Gravity Skimmers Employing Weirs. Several Naval facilities currently use skimming devices based on the concept of an advancing weir.(33) The facilities include the Puget Sound, Long Beach, Norfolk, and Pearl Harbor Naval shipyards and the Newport, Rhode Island Naval Station.

The Puget Sound and Newport units are converted LCM's with an adjustable lip or weir at the forward end. The Pearl Harbor LCM is not an integral unit; auxiliary skimming rafts are towed alongside. Storage/decanting tanks permit separation of the oil from the recovered mixture. A three man crew is required on the Puget Sound Naval Shipyard unit; the constant attention of one of these members is required to adjust the height of the weir.(33) The Norfolk and Long Beach skimmers are similar to the converted LCMs but considerably smaller. The Norfolk unit is not self-propelled. Storage capacity of the skimmers ranges from 6,000 to 10,000 gal. Recovery rate of the Norfolk skimmer is reportedly 600 gal/hr under optimum conditions.(52)

Another gravity skimmer that employs an advancing weir is the WATERWISSER, developed by Shell Chemicals in Holland. Extendable booms on each side of the craft greatly increase the scope during each traverse of an oil slick. The unit can operate at forward speeds up to about two knots. The recovered mixture enters a sump through a vertical slot extending approximately one foot below the water surface. The mixture is subsequently decanted and the water pumped overboard. Oil storage capacity is 20 tons.

Gravity flow or advancing weir devices are generally sensitive to environmental factors, particularly waves. One advantage is that the oil-water mixture entering the skimmer causes a current in front of the skimmer that results in a net inflow--toward the sump--of surface oil and water from an appreciable distance.(33) The size and characteristics of present units make their effectiveness in limited access areas unsatisfactory. Another disadvantage of large self-propelled units is that routine maintenance or breakdowns can remove the unit from service for extended periods. The Puget Sound Naval Shipyard unit was reportedly out of service for two months while repairs were being made.(53)

Disposal of Recovered Material

The disposal of recovered petroleum products, particularly if mixed with sorbents or debris can be extremely expensive if nearby facilities are not available to reclaim or otherwise utilize the oil. Most recovered oil mixtures can be consumed as fuel in industrial or ship power plants that have special provisions for this source of fuel. Most Naval shipyards and other Naval facilities recover petroleum products from other operations such as tank cleaning and, therefore, have adequate disposal facilities available.

Products recovered from areas where normal disposal facilities are not available generally necessitate disposal at inland sites (landfill). Another alternative is burning, but normally the smoke generated is very objectionable unless very high temperature furnaces are available. Agglomerated mixtures of oil and sorbents, such as straw, cannot normally be burned without a considerable drying period due to the water present in the sorbent. The sorbed mixture cannot be pumped and, thus, requires loading into containers or dumptrucks by manual methods.

Landfill sites must be carefully selected to insure that contamination of groundwater does not occur and environmental factors such as heavy rains or storm runoff do not pollute the area outside the disposal site. During handling, transfer, or storage of agglomerated mixtures, it is often advisable to cover the area of operation with plastic sheets to prevent contamination of shoreside areas.

Potential Oil Treatment and/or Recovery System Combinations

The complexity of a recovery system varies greatly over the range of potential equipment, material and techniques. Three classifications of systems exist:

- Chemical
- Chemomechanical
- Mechanical (or Physical).

Chemical methods include those which treat the slick with chemical agents or materials and do not require subsequent mechanical recovery. Included within this classification are methods employing chemical dispersants, burning *in situ*, enhanced degradation (biological or chemical), and sinking.

Chemomechanical methods include those which employ both chemical and mechanical or manual means of recovery. Included within this classification are processes in which the oil is sorbed or gelled and subsequently retrieved by mechanical or manual means.

Mechanical recovery methods are those which employ only mechanical or manual means to recover the product, such as skimmers, suction devices, and rotary drums or endless belts.

The delineation of total systems will include combinations of the general types of available equipment and materials within each classification. The potential systems identified within each classification will be examined both with and without oil containment devices. Systems to be considered will include both permanent and emergency containment installations.

Chemical Systems

a. Chemical dispersants applied directly to the slick with sufficient auxiliary agitation available.
b. System (a) + containment boom.
c. Chemical burning agents applied directly to the slick.
d. System (c) + containment boom.
e. Sinking agents applied directly to the slick.
f. System (e) + containment boom.
g. Enhanced degradation (exclusive of chemical dispersants) by the addition of microorganisms, etc.

Chemomechanical Systems

a. Sorbents/suction pump.
b. System (a) + containment boom.
c. Sorbents/conveyor
d. System (c) + containment boom
e. Sorbents/manual retieval
f. System (e) + containment boom
g. Gellants/conveyor
h. System (g) + containment boom
i. Gellants/manual retrieval
j. System (i) + containment boom

Mechanical Systems

a. Rotating drums
b. System (a) + containment boom
c. Endless belt
d. System (c) + containment
e. Suction devices
f. System (e) + containment
g. Advancing gravity skimmer or weir
h. System (g) + containment boom

Effectiveness Evaluation

The performance criteria and parameters which define the range of spill situations considered credible in this study have

been combined to form a matrix, Figure 3, to enable a comparative effectiveness analyses of potential systems. Each worksheet (shown in Appendix C) refers to one postulated system; the sum of the index points for that system then is a comparative measure of the ability of that system to meet all of the criteria.

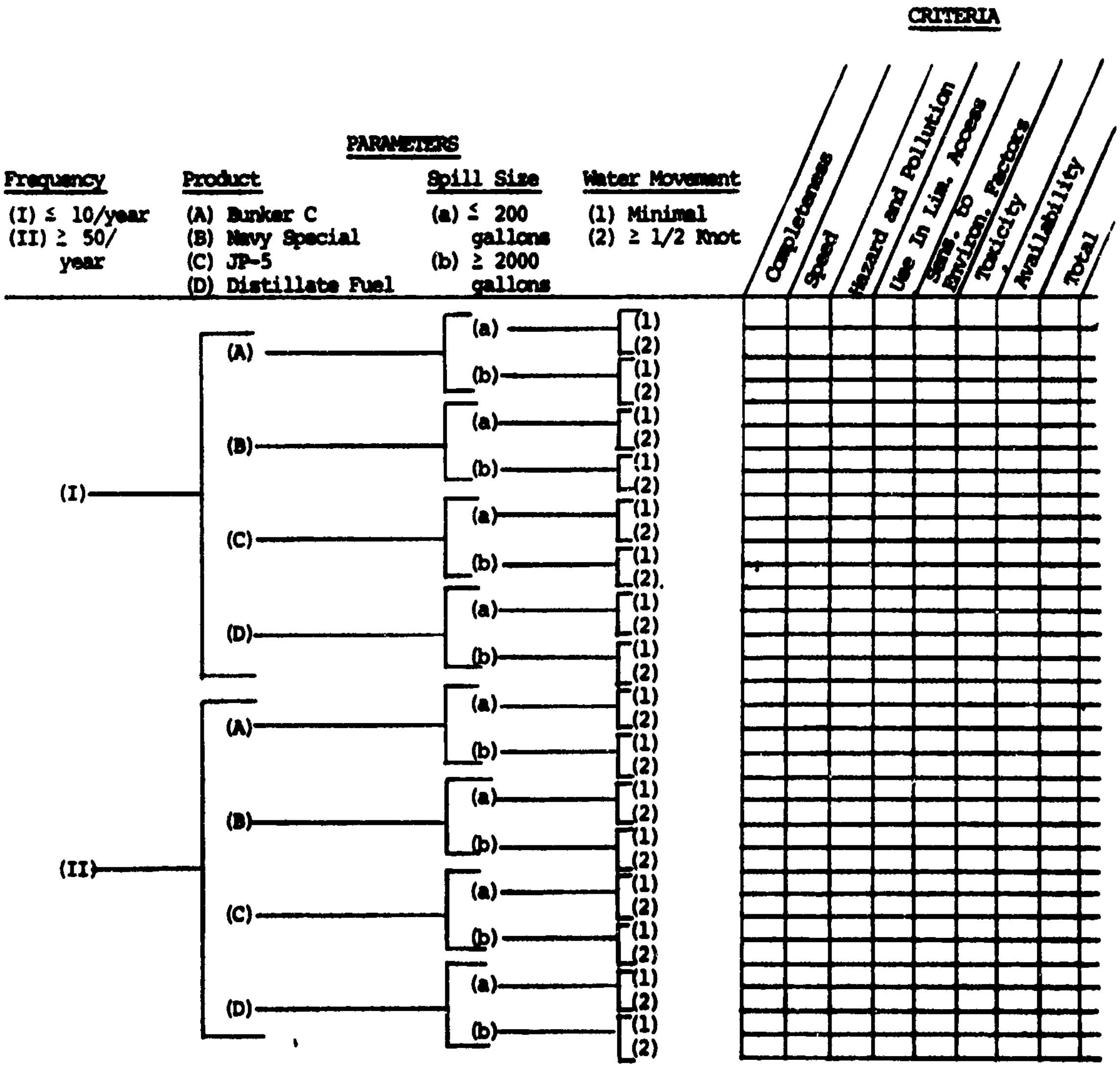
The comparisons of all systems indicates that 12 of the 27 systems considered are clearly superior (over 100 points) when all of the criteria are considered. The potential systems, in descending order of effectiveness, are as follows:

1) Sorbents/manual retrieval plus containment. (144)
2) Gellants/manual recovery plus containment. (144)
3) Suction devices plus containment. (144)
4) Chemical dispersants plus containment. (141-1/2)
5) Sorbents/conveyor plus containment. (128)
6) Gellants/conveyor plus containment. (128)
7) Endless belt on water surface plus containment. (128)
8) Chemical dispersants applied directly to the slick. (126)
9) Sorbents/portable suction device plus containment. (120)
10) Rotating drum or endless belt (nonsorbent surface) plus containment. (112)
11) Gravity skimmer or weir plus containment. (112)
12) Rotating drum or endless belt (sorbent surface) plus containment. (112)
13) Sorbents/portable suction device. (82)
14) Gravity skimmer or weir. (81)
15) Chemical burning agents plus containment. (80)
16) Sinking agents. (76)
17) Sinking agents plus containment. (76)
18) Sorbents/conveyor (self-propelled). (75)
19) Gellants/conveyor (self-propelled). (74)
20) Suction devices (portable). (74)
21) Endless belt on water surface (self-propelled). (71)
22) Rotating drum (nonsorbent surface) (self-propelled). (51)
23) Gellants/manual retrieval. (50)
24) Sorbents/manual retrieval. (47)
25) Rotating drum with sorbent surface. (38)
26) Chemical burning agents. (0)
27) Enhanced degradation (addition of bacteria, enzymes, etc) (-24)

All but one (No. 8) of the above systems employ containment for optimum effectiveness, and even this system is improved when a boom is employed. It is, therefore, apparent that containment of the slick is desirable in virtually every spill of petroleum products. The principal variation among mechanical systems is their capability to function in limited access areas.

FIGURE 3. Effectiveness Analysis Worksheet

SYSTEM:



It must be recognized that the rating on the worksheet covers the performance over a wide range of spill situations and, therefore, the potential systems considered are applicable to all Naval installations in general. Certain Naval facilities, where the range of the parameters is greatly restricted, may be evaluated in terms of the parameters or restrictions unique to that facility. For example, facilities (such as Naval Air Stations) in which spills of only one or two of the products considered are likely should be considered on an individual basis to analyze the potential equipment.

Other controlling factors which can exist in individual facilities include: state or local pollution control regulations, port or harbour authority policy, the proximity of valuable shellfish or fin fish areas, or recreation beaches. Any of these factors can eliminate an otherwise effective system from contention.

It should also be recognized that in some cases the criteria can vary with the parameters, or can be dependent on each other. An example of the variation with changing parameters is that much more relative speed is required for a large spill with a considerable amount of water movement than for a small spill under similar conditions.

The parameters can also have different meanings depending on the type of system being considered. For a chemical system, moving water aids in dispersing to a point that the spilled material will not reappear and cause further pollution, while in a mechanical system the water movement is a hindrance.

An example of the independence of criteria is that in situations where currents are significant, the speed and completeness of treatment are interrelated in that completeness is not possible unless the slick can be recovered very rapidly, especially with a lighter product. Hazard and pollution are related to speed and completeness when the water is moving because objects distant from the source can be contaminated if the recovery is not effected immediately and completely.

Other notes of this type, developed during the effectiveness compilation, are given in the following paragraphs.

<u>Completeness of Removal</u>

<u>Chemical Systems</u> - Implies that the oil is essentially completely dispersed from the water surface and does <u>not</u> reappear at a later time. This means that in calm or unflushed areas the chemicals do not necessarily do a complete long term job as they may reappear.

Chemomechanical and Mechanical Systems - Implies that the system removes the oil from the water surface before it spreads or drifts out of range. Therefore, these systems must operate more rapidly on spills of lighter products. Also, the system must be capable of removing the oil accumulated around obstructions or booms. This is not the same as operating in limited access areas. For example, rotating drums have little or no ability to draw heavy or very light oils from the surrounding area and therefore, will not do an essentially complete job.

Speed of Removal

Speed often is an essential factor in completeness, i.e., the slick will spread too thin if it can't be recovered in time. Speed also implies that the work can be done within daylight hours.

Hazard and Pollution - Includes water surface pollution to waterfowl, facilities and private boats (i.e., damage to recreation such as swimming), fire danger, air pollution.

If a chemical dispersant reappears some time after treatment the pollution can be great.

Sinking agents which release the oil at a later time are similarly ineffective.

System Use in Limited Access - Ability to manuever and get into tight spaces. Also ability to pick up accumulated oil off a boom and operability in shallow water for mechanical system.

Sensitivity to Environmental Factors - Is the system itself sensitive to waves, etc. or does its capability for retrieval decrease?

Toxicity - Applies only to chemicals. Toxic when spread over a small area with minimal tidal action or currents. Excludes water fowl.

Availability - Any self-propelled system must be penalized in this respect because the propulsion unit is bound to break down or require periodic maintenance. Portable gear is superior because it can use other vessels. Also outboard motors are preferred because they can be replaced.

COST ANALYSES OF THE MOST EFFECTIVE SYSTEMS

Assumptions and Basic Costs

The twelve systems that best fulfill the performance criteria for the full range of parameters are to be economically evaluated. (See Section E-4.) The cost base is to be dollars per gallon of oil treated or recovered for each of two spill situations: (a) infrequent (≤10 per year) small spills (≤200 gal) including one spill up to 2000 gal, and (b) frequent (≥50 per year) small spills (≤200 gal) and infrequent (≤10 per year) large spills (up to 2000 gal).

Only systems capable of rapid application after a spill incident will be evaluated, because it is impractical in most Naval installations to provide permanent containment barriers in all areas that a spill could occur. Thus, pneumatic barriers, which provide an efficient (although not necessarily inexpensive) means of containment, will not be considered because of the lack of emergency deployment capability.

Certain cost data are common to several or all systems. For example, hourly labor charge rates will be assumed for personnel and most non-expendable equipment, when possible. This basis provides a readily comparable number that can be applied in all instances. The hourly charge rate of equipment will be derived from either commercial rental rates or the cost of new equipment depreciated over its expected life. Some equipment charges (such as booms) will be prorated per spill, rather than on an hourly rate, based on procurement costs depreciated over the expected life.

Also, equipment charges have been adjusted to include accepted industrial rates for mechanical machinery (6% of acquisition cost/year).

Assumed costs of equipment, material and labor common to several or all systems include:

1. Personnel Billing Rate — $10/man-hr

   Conservative estimate of the cost per man-hr, based on an eight hour day and including overhead and fringe benefits.

2. Containment Booms — $6 ft or $9000/system

   Based on a length of 1500 ft required to encircle a spill of JP-5 within 10-15 min following release. JP-5 has the greatest rate of spreading of the products considered. The boom must be capable of either being towed

at speeds of approximately 10 knots or rapidly deployable from the deck of a workboat in order that the boom can be in place within 15 min following a spill. Deployment costs per incident, including setup, positioning, recovery and cleanup, are estimated to require four man-hr plus two hr of small boat time and $10 of miscellaneous materials for cleanup, etc. Thus, the total cost per incident is about $60. An expected useful boom life of one yr will be used for consideration of infrequent spills and two yr for considerations of frequent spills.

3. <u>Disposal</u> $0.50/gal

Disposal can represent a significant cost when suitable disposal facilities are not available in proximity to the scene of a spill. However, most potential spill sites are equipped with adequate disposal facilities and, therefore, the $0.50 represents the cost of transporting, transferring and the cleanup of transfer vessels. Recovered petroleum products are utilized as fuel for power plants at many installations. Unique systems, such as those employing bulky sorbents, will necessitate special disposal techniques and additional cost per gal will be correspondingly added.

4. <u>Auxiliary Surface Craft</u>

Small	$3/hr
Intermediate	$12/hr (with crew)
Large	$18/hr (with crew)

Several sizes and types of surface craft are required for the different systems. Manual retrieval can be effected from two-man punts or similar craft about 16 ft in length. These craft can also be used for boom deployment. The cost of this type of craft with auxiliary power, such as a small outboard motor, is assumed to be $4/hour. Intermediate-size craft, approximately 20 to 30 ft long, are sufficient for application of chemical dispersants and other uses that do not require large volume storage tanks. The cost of this type of craft is assumed to be $12/hr, including crew. Systems that recover considerable amounts of water with the recovered oil necessitate large craft with decanting or separation and storage tanks for the oil. A combined preparation and/or storage capacity up to 10,000 gal may be required and, therefore, these craft would undoubtedly exceed 30 ft in length. The cost is assumed to be $18/hr, with crew.

5. <u>Sorbents</u> Commercial bulk materials (nonfoam) $0.30/gal
Straw $0.03/gal
Polymer foams $0.15/gal

Three general classifications of sorbent materials will be considered: (1) commercial bulk material such as perlite, vermiculite talc, and shreaded bark, (2) straw, and (3) polymer foams such as polyurethane, polypropylene, polystyrene and polyethylene. The cost of commercial bulk materials is typically $100 to $250/ton and they will absorb three or more times their own weight of oil; thus, the cost is approximately $0.30/gal. Straw is almost universally available (reportedly not available in Hawaii) at about $30/ton. It is assumed to absorb five times its own weight of oil and therefore the cost is approximately $0.30/gal. The employment of "soft" polymer foams, from which oil can subsequently be recovered, is of great potential if systems for broadcasting the sorbent and efficiently recovering it from the water surface become available. Polyurethane foam can theoretically absorb in excess of 90% of its volume and over 100 times its weight of oil. The cost of polyurethane foam ("soft") is approximately $0.75/lb and one pound will typically absorb about 5 gallons under field conditions, and making the cost about $0.15/gallon.

6. <u>Gelling Agents</u> $2.50/gal

At least one gelling agent is available commercially ("Spill-Away," manufactured by the Yosemite Chemical Company) which is relatively non-toxic to marine life and facilitates manual and perhaps mechanical recovery. The cost of this product is approximately $2.50/gal and the application ratio of gellant to water ranges from about 1:2 to 1:1. A conservative value of 1:1 will be assumed for all products, making the cost $2.50/gal of gelled oil.

7. <u>Chemical Dispersants</u> $1/gal

The effectiveness of chemical dispersants, application ratios, toxicity, and stability is highly controversial because of the abundant conflicting information, based primarily on either profit motives or anti-pollution sentiment. Several hundred products can potentially be employed to disperse oil and the range in price is from about $1.50 to $4.50/gallon. The effective application ratio is highly dependent on several diverse factors, but is generally about 1 part dispersant to 3 to 4 parts oil. The cost of the application equipment (exclusive of vessel) will be factored into the price per gallon because it varies widely with different products. Assuming an average cost of $3/gal and 3 to 4 parts of

oil dispersed per gal, plus application equipment, the cost of oil dispersed is approximately $1/gallon. This cost per gal is somewhat substantiated by other cost estimates.[44]

The two spill situations previously described will be designated as Situation A (infrequent small spills not exceeding 200 gal and one large spill up to 2000 gal) and Situation B (frequent small spills not exceeding 200 gal and infrequent large spills up to 2000 gallons). The total maximum yearly volume of oil to be recovered in Situation A is 4000 gallons. The maximum integrated recovery volume for Situation B is 30,000 gallons.

Cost Compilation

1. Sorbents/Manual Retrieval Plus Containment Booms

Situation A (10 incidents, total volume <4,000 gal):		
Containment boom:		
($9,000/2 yr) + (10 incidents) ($60)		$ 5,100
Sorbents:		
Commercial bulk materials:		
(4,000 gal) ($0.30/gal)	$ 1,200	
Spreading, 40 man-hr	400	
Recovery, 200 man-hr	2,000	
	$ 3,600	
Straw:		
(4,000 gal) ($0.03/gal)	$ 120	
Spreading, 40 man-hr	400	
Recovery, 200 man-hr	2,000	$ 3,000 (avg)
	$ 2,520	
Polymer foams:		
(4,000 gal) ($0.15/gal)	$ 600	
Spreading, 40 man-hr	400	
Recovery, 200 man-hr	2,000	
	$ 3,000	
Surface vessels:		
60 hr of small craft @ $4/hr		240
20 hr of intermediate craft @ $12/hr		240
Disposal:		
(4,000 gal) ($0.50/gal)		2,000
	Total Cost	$10,580

This represents a cost of approximately $1,060 per incident or $2.65 per gal of oil recovered.

Situation B (~60 incidents, total volume ~40,000 gal):

Containment boom:		
$9,000 + (60 incidents) ($60)		$12,600
Sorbents:		$25,000 (avg)
Commercial bulk materials:		
(40,000 gal) ($0.30/gal)	$12,000	
Spreading 300 man-hr	3,000	
Recovery 1500 man-hr	15,000	
	$30,000	
Straw:		
(40,000 gal) ($0.03/gal)	$ 1,200	
Spreading 300 man-hr	3,000	
Recovery 1500 man-hr	15,000	
	$19,200	
Polymer foams:		
(40,000 gal) ($0.15/gal)	$ 6,000	
Spreading 300 man-hr	3,000	
Recovery 1500 man-hr	15,000	
	$24,000	
Surface Vessels:		
600 hr of small craft @ $4/hr		2,400
200 hr of intermediate craft @ $12/hr		2,400
Disposal:		
(40,000 gal) ($0.50/gal)		20,000
	Total Cost	$62,400

This represents a cost of approximately $1,060 per incident or $1.60 per gal of oil recovered.

2. Gellants/Manual Recovery Plus Containment Boom

Situation A:

Containment boom	$ 5,100
Gelling agents:	
(4,000 gal) ($2.50/gal)	10,000
Application:	
40 man-hr	400
Recovery:	
200 man-hr	2,000
Surface vessels:	
60 hr of small craft @ $4/hr	240
20 hr of intermediate craft @ $12/hr	240
Disposal:	
(4,000 gal) ($0.50/gal)	2,000
Total Cost	$19,980

This represents a cost of approximately $2,000 per incident or approximately $5.00 per gal of oil recovered.

Situation B:

Containment boom	$ 12,600
Gelling agents: (40,000 gal) ($2.50/gal)	100,000
Application: 300 man-hr	3,000
Recovery: 1500 man-hr	15,000
Surface vessels:	
600 hr of small craft @ $4/hr	2,400
200 hr of intermediate craft @ $12/hr	2,400
Disposal: (40,000 gal) ($0.50/gal)	20,000
Total Cost	$147,100

This represents a cost of approximately $2,600 per incident or approximately $3.90 per gal of oil recovered.

3. Suction Devices Plus Containment Boom

A range of suction devices are available to remove oil from the water surface. Septic tank cleaning contractors charge approximately $50 to empty a 1000 gal tank. This method is cheap and efficient if the oil can be swept or dragged with booms to a convenient pickup location. The cost of recovering a 200 gal spill by this means is estimated to be $100, including disposal, and $500 for a 2000 gal spill, including disposal. A new vacuum pickup system being marketed by Neirad Industries consists of a fan-shaped flexible suction head that floats on the water surface. The head can be located up to 80 ft from the diaphragm type pump. Two capacities are available: 60 and 160 gpm. Percentage of oil recovered is estimated to be between 20 and 80% if the slick is condensed. Prices are $3,750 for the smaller system and $7,450 for the larger. The system does not include storage tanks and, therefore, the procurement price for the suction device would be about $4,000 and $8,000, respectively. Two operating personnel are required and the suction head can be maneuvered from a surface craft, thus permitting retrieval of oil from inside a boom while the recovery ship remains outside. The new vortex axial flow device of Reynolds Metals Company is assumed to be in the same price range. Assumed life of these devices is four years for infrequent cases and two years for frequent cases.

Situation A:

Containment boom	$ 5,100
Suction device cost: $8,000 ÷ 4 yr (or $100/spill × 10 spills for a tank truck)	2,000
Personnel required: (4 man-hr) (10 spills)	400
Surface vessels:	
One large craft 20 hr @ $18/hr	360
One small craft 40 hr @ $4/hr	160
Disposal: (4,000 gal) ($0.50/gal)	2,000
Total Cost	$10,020

This represents a cost of approximately $1,000 per incident or $2.50/gal of oil recovered.

Situation B:

Containment boom	$12,600
Suction device cost: $8,000 ÷ 2 yr	4,000
Personnel requirements: (6 man-hr/spill) (60 spills)	3,600
Surface vessels:	
One large craft 150 hr @ $18/hr	2,700
One small craft 300 hr @ $4/hr	1,200
Disposal: (40,000 gal) ($0.50/gal)	20,000
Total Cost	$44,100

This represents an approximate cost of $735 per incident or $1.10/gal of product recovered.

4. <u>Chemical Dispersants Plus Containment Boom</u>

Situation A:

Containment boom	$ 1,500
Chemical dispersants: (4,000) ($1/gal)	4,000
Personnel: (4 man-hr) (10 spills)	400
Surface craft:	
One intermediate craft 25 hr @ $12/hr	300
	$ 9,800

This represents an approximate cost of $980 per incident or $2.45/gal of oil dispersed.

Situation B:

Containment boom	$12,600
Chemical dispersants: (40,000 gal) ($1/gal)	40,000
Personnel: (4 man-hr) (60 spills)	2,400
Surface craft: One intermediate craft 150 hr @ $12/hr	2,800
Total Cost	$57,800

This represents an approximate cost of $965 per incident or approximately $1.45/gal of oil dispersed.

5. Sorbents/Conveyor Plus Containment Boom

A mechanical conveyor for the recovery of sorbents or gelled material has yet to be designed specifically for the recovery of an agglomerated mixture of oil and sorbents or gelled petroleum products. Devices intended for similar purposes such as aquatic weed or kelp harvesting could be adapted to the recovery of these agglomerated mixtures. The cost of these units is estimated to be $50,000. The estimated useful life is four yr in infrequent spill areas and two yr where frequent spills occur.

Situation A:

Containment boom	$ 5,100
Sorbents (assume $0.10/gal as an average of straw and polymer foams): (4,000 gal) ($0.10/gal)	400
Mechanical recovery:	
Equipment $50,000/4 yr	12,500
Labor, 40 man-hr	400
Surface vessels: 20 hr of small craft @ $4/hr	80
Disposal: (4,000 gal) ($0.50/gal)	2,000
Total Cost	$15,780

This represents an approximate cost of $1,580 per incident or approximately $3.95/gal of oil recovered.

Situation B:

Containment boom	$ 12,600
Sorbents:	
(40,000 gal) ($0.10/gal)	4,000
Spreading, 300 man-hr	3,000
Mechanical recovery:	
Equipment $50,000/2 yr	25,000
Labor, 250 man-hr	2,500
Surface vessels:	
150 hr of small craft @ $4/hr	600
Disposal:	
(40,000 gal) ($0.50/gal)	20,000
Total Cost	$ 67,700

This represents a cost of approximately $1,130 per incident or $1.67/gal of oil recovered.

6. Gellants/Conveyor Plus Containment Boom

Situation A:

Containment boom	$ 5,100
Gellants:	
(4,000 gal) ($2.50/gal)	10,000
Spreading, 40 man-hr	400
Mechanical recovery:	
Equipment $50,000/4 yr	12,500
Labor, 40 man-hr	400
Surface vessels:	
20 hr of small craft @ $4/hr	80
Total Cost	$ 30,480

This represents an approximate cost of $3,050 per incident or $7.60/gal of oil recovered.

Situation B:

Containment boom	$ 12,600
Gellants:	
(40,000 gal) ($2.50/gal)	100,000
Mechanical recovery:	
Equipment $50,000/2 years	25,000
Labor, 250 man-hr	2,500
Surface vessels:	
150 hr of small craft @ $4/hr	600
Disposal:	
(40,000 gal) ($0.50/gal)	20,000
Total Cost	$163,700

This represents an approximate cost of $2,730 per incident or approximately $4.10/gal of oil recovered.

7. Endless Rope or Belt on Water Surface Plus Containment Boom

The Royal Dutch Shell laboratories at Rijswijk in the Netherlands have developed an oil recovery device which employs an endless oil absorbent "rope" or hose which floats on the water surface. The "rope" or hose which is drawn over the water, absorbs the oil which is subsequently wrung out as the hose is revolved. A self-propelled surface craft with the hose, storage and wringers is estimated to cost $75,000 and have a useful life of six yr in areas of infrequent spills and three yr in areas of frequent spillage.

Situation A:

Containment Boom	$ 5,100
Mechanical recovery:	
$75,000/6 yr	12,500
Labor, 40 man-hr	400
Surface vessels:	
20 hr of small surface craft @ $4/hr	80
Disposal:	
(4,000 gal) ($0.50/gal)	2,000
Total Cost	$20,080

This represents an approximate cost of $2,000 per incident or $5/gal of recovered oil.

Situation B:

Containment Boom	$12,600
Mechanical recovery:	
$75,000/3 yr	25,000
Labor, 250 man-hr	2,500
Surface vessels:	
150 hr of small craft @ $4/hr	600
Disposal:	
(40,000 gal) ($0.50/gal)	20,000
Total Cost	$60,700

This represents an approximate cost of $1,000 per incident or $1.50/gal of oil recovered.

8. Chemical Dispersants Applied Directly to the Slick

Situation A:

Chemical dispersants:	
(4,000 gal) ($1/gal)	$ 4,000
Labor:	
(4 man-hr) (10 spills)	400
Surface craft:	
One intermediate craft 25 hr @ $12/hr	300
Total Cost	$ 4,700

This represents an approximate cost of $470 per incident or $1.20/gal of oil dispersed.

Situation B:

Chemical dispersants:	
(40,000 gal) ($1/gal)	$40,000
Labor, 300 man-hr	3,000
Surface craft:	
One intermediate craft 200 hr @ $12/hr	2,400
Total Cost	$45,400

This represents an approximate cost of $760 per incident or $1.10 per/gal of oil dispersed.

9. Sorbents/Portable Suction Device Plus Containment Boom

A mechanical pumping device capable of recovering finely granulated sorbents from the water surface can be developed if it is not already available. The cost of such a unit is estimated to be $12,000, including storage and decanting tanks, and the expected useful life about four years in areas of low spill frequency and two years where numerous spills occur. An average cost of $0.15/gal will be assumed for sorbents because it is unlikely that straw can be recovered effectively by a suction device.

Situation A:

Containment boom	$ 5,100
Sorbents:	
(4,000 gal) ($0.15/gal)	600
(4 man-hr) (10 spills)	400
Mechanical recovery:	
$12,000/4 yr	3,000
Labor, 4 man-hr × 10 spills	400
Surface vessels:	
One large craft 20 hr @ $18/hr	360
One small craft 40 hr @ $4/hr	160

Disposal:	
(4,000 gal) ($0.50/gal)	$ 2,000
Total Cost	$12,000

This represents an approximate cost of $1,200 per incident or $3/gal of oil recovered.

Situation B:

Containment Boom	$12,600
Sorbents:	
(40,000 gal) ($0.15/gal)	6,000
Labor, 250 man-hr	2,500
Mechanical recovery:	
$12,000/2 yr	6,000
Labor, 360 man-hr	3,600
Surface vessels:	
One large craft 150 hr @ $18/hr	2,700
One small craft 150 hr @ $4/hr	600
Disposal:	
(40,000 gal) ($0.50/gal)	20,000
Total Cost	$54,000

This represents an approximate cost of $900 per incident or $1.35/gal of oil recovered.

10. Rotating Drum or Endless Belt (Non-Sorbent Surface) Plus Containment

The procurement cost of mechanical systems of this general type can vary widely, depending on size and type. However, it is estimated that a typical cost is $80,000 with a useful life of six yr in areas of infrequent spills and three yr where numerous spills occur.

Situation A:

Containment boom	$ 5,100
Mechanical recovery:	
$80,000/6 yr	13,300
Labor, 40 man-hr	400
Surface vessels:	
One small craft 20 hr @ $4/hr	80
Disposal:	
(4,000 gal) ($0.50/gal)	2,000
Total Cost	$20,800

This represents an approximate cost of $2,100 per incident or approximately $5.20/gal of oil recovered.

Situation B:

Containment boom	$12,600
Mechanical recovery:	
$80,000/3 yr	26,600
Labor, 300 man-hr	3,000
Surface vessels:	
One small craft 150 hr @ $4/hr	600
Disposal:	
(40,000 gal) ($0.50/gal)	20,000
Total Cost	$62,800

This represents an approximate cost of $1,050 per incident or approximately $1.60/gal of oil recovered.

11. Gravity Skimmer or Weir Plus Containment Boom

The gravity skimming devices can vary widely depending on the size of the vessel required. A typical cost is estimated to be $60,000, with a useful life of six years in areas of infrequent spills and three years where numerous spills occur.

Situation A:

Containment boom	$ 5,100
Mechanical recovery:	
$60,000/6 yr	10,000
Labor, 40 man-hr	400
Surface vessels:	
One small craft 20 hr @ $4/hr	80
Disposal:	
(4,000 gal) ($0.50/gal)	2,000
Total Cost	$17,580

This represents an approximate cost of $1,760 per incident or $4.40/gal of oil recovered.

Situation B:

Containment Boom	$12,600
Mechanical recovery:	
$60,000/3 yr	20,000
Surface vessels:	
One small craft 150 hr @ $4/hr	600
Disposal:	
(40,000 gal) ($0.50/gal)	20,000
Total Cost	$56,200

This represents an approximate cost of $940 per incident or $1.40/gal of oil recovered.

12. <u>Rotating Drums or Endless Belt (Sorbent Surface) Plus Containment Boom</u>

The cost associated with this system would be nearly identical with similar systems employing non-sorbent surfaces. However, $10,000 will be added to the procurement cost (total $90,000) and depreciated to provide for replacement and service of the foam socks or sorbent surfaces, which are vulnerable to damage.

Situation A:

Containment Boom	$ 5,100
Mechanical recovery:	
$90,000/ 6 yr	15,000
Labor, 40 man-hr	400
Surface craft:	
One small craft 20 hr @ $4/hr	80
Disposal:	
(4,000 gal) ($0.50/gal)	2,000
Total Cost	$22,580

This represents an approximate cost of $2,300 per incident or $5.65/gal of oil recovered.

Situation B:

Containment Boom	$12,600
Mechanical recovery:	
$90,000/3 yr	30,000
Labor, 300 man-hr	3,000
Surface vessels:	
One small craft 150 hr @ $4/hr	600
Disposal:	
(40,000 gal) ($0.50/gal)	20,000
Total Cost	$66,200

This represents an approximate cost of $1,100 per incident or $1.65/gal of oil recovered.

The comparative cost data from the preceding sections is summarized in Table 8.

TABLE 8. Cost Summary

SYSTEM	SITUATION A Cost Per Incident	SITUATION A Cost Per Gallon	SITUATION B Cost Per Incident	SITUATION B Cost Per Gallon
1. Sorbents/Manual Retrieval Plus Containment	$1,060	$2.65	$1,060	$1.60
2. Gellants/Manual Retrieval Plus Containment	2,000	5.00	2,600	3.90
3. Suction Devices Plus Containment	1,000	2.50	735	1.10
4. Chemical Dispersant plus Containment	980	2.45	965	1.45
5. Sorbents/Conveyor Plus Containment	1,580	3.95	1,130	1.67
6. Gellants/Conveyor Plus Containment	3,050	7.60	2,730	4.10
7. Endless Belt on Water Surface Plus Containment	2,000	5.00	1,000	1.50
8. Chemical Dispersant	470	1.20	760	1.10
9. Sorbents/Portable Suction Devices Plus Containment	1,200	3.00	900	1.35
10. Rotating Drums or Endless Belts (Non-Sorbent Surface) Plus Containment	2,100	5.20	1,050	1.60
11. Gravity Skimmer or Weir Plus Containment	1,760	4.40	940	1.40
12. Rotating Drum or Endless Belt (Sorbent Surface) Plus Containment	2,300	5.65	1,100	1.65

IDENTIFICATION OF MOST COST EFFECTIVE SYSTEMS

As can be seen in the previous section the cost in dollars/gal of oil treated varies with the spill size and frequency. The parametric cases used in these analyses are believed to represent the most probable situations--they are intended to represent Naval installations at ports which have a large volume of traffic and fuel transfer operations on the one extreme and those with nominal activities on the other. Cost data were combined with the effectiveness indices by simply dividing the cost/gal of oil treated by the total effectiveness index for each system. These are shown for each of the twelve most effective systems on Table 9. On this table, the system having the lowest cost/effectiveness ratio is the most favorable.

It can be seen that for the more frequent spill case, systems 8, 4, 3, and 1 are the most cost effective. For lower frequency of spillage, systems 3, 8, 1, and 7 are superior. Summation of the cost effectiveness ratios for the two spill frequency situations shows systems 8 and 3 to be most cost effective.

It is concluded, that within the present state-of-the-art, direct application of chemical dispersants (system 8) and a system utilizing a suction device plus a containment boom (system 3) are, overall, most cost effective. Each of these two systems would be expected to be more effective in some situations than in others. Interpretation of the effectiveness analyses allows the selection between these two systems for each set of parameters as shown on Table 10.

This table shows that chemical dispersants applied directly to slicks are superior only when sufficient currents and tidal flushing, or moderately severe water surface conditions, exist at the spill sites.

It is concluded that the most advantageous system for all parameter combinations, except for moderately severe sea states and/or significant tidal flushing and surface currents is the one consisting of a mechanical suction device plus containment booms. For storm conditions, it is reasonable to assume that no oil treatment activities would be attempted. Where local, state, or federal regulations prohibit the use of dispersants, this system should also be employed. If tidal flushing is significant and no contrary restrictions exist, chemical dispersants applied directly to the oil slick, with auxiliary agitation should be used. At most Naval installations where frequent spills have been experienced, both methods should be available--with the mechanical system used when the spill can be contained under calm

TABLE 9. Cost Effectiveness Ratios

System	Effectiveness Index Score	Cost/Gal: A (one 2000 gal + 10-200 gal spills/yr)	Cost/Gal: B (10 2000 gal + 50-200 gal spills/yr)	Cost Effectiveness Ratios: A (one 2000 gal + 10-200 gal spills/yr)	Cost Effectiveness Ratios: B (10 2000 gal + 50-200 gal spills/yr)
1) Sorbents/manual retrieval plus containment boom.	144	$2.65	$1.60	0.0184	0.011
2) Gellants/manual recovery plus containment boom.	144	5.00	3.90	0.0347	0.0271
3) Suction devices plus containment boom.	144	2.50	1.10	0.0174	0.0076
4) Chemical dispersants plus containment boom.	141-1/2	2.45	1.45	0.0173	0.0125
5) Sorbents/conveyor plus containment boom.	128	3.95	1.67	0.0308	0.0131
6) Gellants/conveyor plus containment boom.	128	7.60	4.10	0.0595	0.032
7) Endless belt on water surface plus containment boom.	128	5.00	1.50	0.0391	0.0117
8) Chemical dispersants applied directly to the slick.	126	1.20	1.10	0.00955	0.00875

TABLE 9. (contd)

System	Effectiveness Index Score	Cost/Gal A (one 2000 gal + 10-200 gal spills/yr)	Cost/Gal B (10 2000 gal + 50-200 gal spills/yr)	Cost Effectiveness Ratios A (one 2000 gal + 10-200 gal spills/yr)	Cost Effectiveness Ratios B (10 2000 gal + 50-200 gal spills/yr)
9) Sorbents/portable suction device plus containment boom.	120	3.00	1.35	0.025	0.0125
10) Rotating drum or endless belt (non-sorbent surface) plus containment boom.	112	5.20	1.60	0.0464	0.0143
11) Gravity skimmer or weir plus containment boom.	112	4.40	1.40	0.0393	0.0125
12) Rotating drum or endless belt (sorbent surface) plus containment boom.	112	5.65	1.65	0.0415	0.0147

TABLE 10. Most Cost Effective Systems for Parameter Combinations

PARAMETERS

Frequency	Product	Spill Size	Water Movement	Most Effective System
(I) ≤ 10/year (II) ≥ 50/ year	(A) Bunker C (B) Navy Special (C) JP-5 (D) Distillate Fuel	(a) ≤ 200 gallons (b) ≥ 2000 gallons	(1) Minimal (2) ≥ 1/2 Knot	3-Suction Device + Containment 8-Chemical Dispersant
(I)	(A)	(a)	(1)	3
			(2)	8
		(b)	(1)	3
			(2)	3
	(B)	(a)	(1)	3
			(2)	8
		(b)	(1)	3
			(2)	3
	(C)	(a)	(1)	3
			(2)	8
		(b)	(1)	3
			(2)	3
	(D)	(a)	(1)	3
			(2)	8
		(b)	(1)	3
			(2)	3
(II)	(A)	(a)	(1)	3
			(2)	8
		(b)	(1)	3
			(2)	3
	(B)	(a)	(1)	3
			(2)	8
		(b)	(1)	3
			(2)	3
	(C)	(a)	(1)	3
			(2)	8
		(b)	(1)	3
			(2)	3
	(D)	(a)	(1)	3
			(2)	8
		(b)	(1)	3
			(2)	3

sea conditions. The dispersant system should be used during periods of tidal flow or moderate sea conditions. If both systems were available, the use of booms, which are part of the mechanical system, would be beneficial for use with the dispersant system.

It should be noted that Bunker C at low temperature is probably not amenable to treatment by any of the systems considered in this study. If it is below its pour point (30 to 60 °F) Bunker C cannot be effectively pumped, mechanically picked up, or mixed with dispersants or sorbents. Under this condition, spills of this material, can probably be treated only by manual retrieval. This does not appear to be totally undesirable when the physical characteristics (congealed, nonspreading, nondiffusing, slow moving) and the associated minimal threats to marine life and property are considered.

FUTURE WORK NEEDED

During the course of this study, numerous potential improvements in the methods, materials, and equipment used for removal of spilled Bunker C, Navy Special, Distillate Fuel, and JP-5 from port and harbor water surface were identified. These include innovations. further development of spill technology for the petroleum products used by the Navy, and spill countermeasures management. The items believed feasible and capable of improving the effectiveness and economics of treatment of spills within the scope of this study are:

Innovations

- Dispersants which require application rates approximating those for the more effective current materials but whose toxicity thresholds are on the order of 1000 ppm. Such materials are needed to accomplish "final polishing" after initial cleanup, by other methods, of spills of rapidly spreading materials such as Distillate Fuel and JP-5.
- Development of automated mechanical methods of collecting and removing (from water surfaces), oil agglomerates which have been formed by the use of sorbents. It seems probable that kelp or aquatic harvesting equipment could be adapted for this purpose.
- Develop more effective methods of mixing dispersants or sorbents with a slick. Current methods do not provide continuous agitation for several minutes after the application of dispersants, as is often necessary for permanent dispersal. Improved mixing capability would also tend to reduce the field application dosage required.

- Development of *in situ* methods of producing polyurethane or other foams which have optimal void volume, pore size, and density, with regard to the oil pollutants of concern to the Navy.
- Development of a rapidly deployable integral oil pickup-containment device.
- Consideration of equipment and techniques for application, now under development and for which no data were available at the time of this study. Many of these items were mentioned in the text and included the "Vortex Pump," p. 4-45, the Corpus Christi Refinery Terminal Fire Department Propelled Boom," p. 4-36, and the "Air Lift System," p. 4-45.

Spill Technology

- Development of accurate methods for measurement or estimation of spill volumes. This is particularly important for treatments involving the use of dispersants, sorbents, or gellation agents in order to predetermine required application rates. Refinement of the Blokker technique for estimation of slick thickness after spillage, to take into account temperature, oil properties, and evaporation, appears to be a possible estimation method.
- Development of standardized effectiveness and bioassay tests for chemical dispersants which cover the range of possible spill materials. The present Navy chemical dispersant efficiency test (MIL-S-22 864) includes only tests with Navy Special.
- Comparative evaluation of materials locally available at Naval Installations and which are capable of serving as sorbers or agglomerants. This would be particularly valuable in the remote event of a massive spill and should include the range of possible spill materials and such materials as straw, fly ash, pumice, and volcanic ash.

Spill Management

- Installation of permanent air barrier-mechanical boom combinations at fueling stations or other sites where operational considerations indicate frequent spillage.
- Installation of passive surface water spray jet systems that can be actuated in an emergency on structures having piling supports. By this method, spill material could be washed from under or prevented from penetrating, the structure.
- Placement of emergency containment equipment and operations under control of the fire department at each installation.

- Provision for a formal training program for personnel charged with spillage countermeasures at all Naval installations. Program should be developed for each site, stress conservation and hazards aspects, and be presented by recognized authorities.
- Development of a detailed contingency plan for coping with both nominal and massive spills at each Naval installations for all petroleum products potentially involved in spillage. Fall back positions should be included.

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APPENDIX A

DETAILED PORT AND ENVIRONMENTAL DATA

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DETAILED PORT AND ENVIRONMENTAL DATA

This appendix contains the basic information from which the report section entitled "Reference Ports and Harbors" was derived. It includes detailed geographic and hydrologic information on ports used by U.S. Naval craft in the form of charts, meteorological data, and tabulated data describing the types of resources vulnerable to damage by oil spillage at specific ports.

Table A-1 lists the environmental and physical features significant to this study. Table A-2 lists the nearby port features, including the resources which would be threatened by oil spillage, at selected west coast Naval installations.

The data given on Table A-3 were obtained from the Decennial Census of United States Climate, Summary of Hourly Observations.

Table A-4 is a summary of predicted wave dimensions expected to prevail at least 90% of the time at ports believed most susceptible to petroleum product spillage.

Figures A-1 through A-14 illustrate the geography of ports and harbors mentioned in the tables.

The Pacific Coast of the United States provides a spectrum of domestic ports and harbors representative of facilities accessible to United States Naval vessels (with the exception of the Panama Canal Zone where municipal water supplies can be affected by an oil release). Representative ports and harbors whose characteristics provide this broad spectrum are presented below:

Puget Sound, located on the Pacific Coast in the northwest corner of the State of Washington, is the largest of the protected bodies of water, covering an area of 767 square nautical miles and having a tidal prism of 1.27 cubic nautical miles. Both the mean sea temperature and the mean air temperature are 50 °F. The 1157 miles of shoreline include both recreational and rocky beaches and numerous precipitous cliff-like boundaries. Average mean and maximum tides are 7.6 ft and 14.8 ft. Prevailing winds are south or southwest and average 8 to 10 knots. The high winds are also from the south and occasionally exceed 60 knots. Annual precipitation is about 40 in.

All of the naval facilities located on Puget Sound are on open faces of large, relatively deep bodies of water. Oil

spillage at these facilities can migrate over extensive areas, depending on environmental conditions such as wind and surface currents.

The Puget Sound Naval Shipyard is located on the northern shore of the Sinclair Inlet, which is approximately 1.2 miles wide by 5 miles long. The maximum current at the shipyard is 1.5 knots. There are approximately 13 miles of shore line nearby with sparse industrial facilities and numerous floats for small craft. Surface-borne contaminants from this region could contact areas containing recreational beaches, shell fish grounds, and a variety of marine life.

The Naval Fuel Depot at Manchester is located just south of Orchard Point on the eastern shore of Puget Sound, which is approximately 5 miles wide at this point. The maximum current at the fuel depot is 1.2 knots. There are 3 miles of shore line nearby with sparse industrial facilities. Surface-borne contamination from this region could contact areas containing recreational beaches, shell fish, and a variety of marine life including commercial fisheries.

The Naval Supply Center at Seattle is located on the north shore of Elliott Bay which widens Puget Sound to approximately 7.5 miles at this point. The current at the Supply Center is weak and rarely exceeds 0.5 knots. There are 13 shore line miles of adjacent dense industrial facilities including major shipping berths. Tidal flushing from this region comes in contact with areas containing recreational beaches and a variety of marine life including sports fisheries.

The Naval Torpedo Station at Keyport is located on the west shore of the entrance to Liberty Bay, which is approximately 2 miles long by 1 mile wide. The station is on the north end of Port Orchard Passage, a body of water 1 mile wide by 11.5 miles long. The maximum current at the Torpedo Station is 1.1 knots. There is approximately 1 mile of sparse industrial shore line facilities nearby. Surface-borne contaminants from this region come in contact with the areas containing recreational beaches, commercial oyster beds, and a variety of fisheries.

The Naval Ammunition Depot at Bangor is located on the eastern shore of Hood Canal, which is approximately 2 miles wide by 59 miles long. The maximum current at the Ammunition Depot is one knot. Surface-borne contaminants from this region come in contact with areas containing recreational beaches, commercial shell fish grounds, and a variety of marine life, including commercial fisheries. The intertidal zone of this region of Hood Canal is heavily populated with oysters and clams. (Refer to Figure A-2.)

San Francisco Bay, located on the Pacific Coast in the north-central region of the state of California, is the second largest of the protected bodies of water on the Pacific Coast, covering an area of 309 square nautical miles and having a tidal prism of approximately 0.26 cubic nautical miles. The mean sea temperature is 55.6 °F and the mean air temperature is 56.0 °F. The 160 nautical miles of shore line include estuaries, mud flats, rocky beaches, a few recreational beaches and several areas of dense industrial facilities. Average mean and maximum tides are 4 and 10 ft. Prevailing winds are west-northwest and average 9 to 11 knots. The high winds are southwest and occasionally exceed 54 knots. Annual precipitation is 18.7 in. A geographic chart of this area is shown in Figure A-3.

All of the Naval facilities on San Francisco Bay, with the exception of the Mare Island Naval Shipyard, are located on open faces of the large main body of water. Oil spillage at these facilities can migrate over extensive areas, depending on environmental conditions such as wind and surface currents. Oil spillage migration from the Mare Island Naval Shipyard is tide dependent, migrating up the Napa River into estuarine areas on the flood tide and over extensive areas of San Francisco Bay on the ebb.

The Mare Island Naval Shipyard is located on the Mare Island Strait, a body of water 2.8 miles long by 1100 ft wide, fed by the Napa River and emptying into the northeast corner of San Francisco Bay. The maximum current at the shipyard is 2.4 knots. Both sides of the 2.8 mile strait are occupied by either Naval or industrial facilities, including numerous small craft moorage. Dense industrial facilities are located one mile south from the Mare Island Outlet. Tidal flushing from this area comes in contact with widespread estuarine areas, mud flats, and areas used for sport fisheries.

The Hunters Point Naval Shipyard is located on the eastern shore of San Francisco Bay due west of the Metropolitan Oakland International Airport, across a 5.5 mile width of the Bay. The maximum current at the shipyard is 1.8 knots. There are 8 shore line miles of adjacent industrial facilities including major shipping berths. Tidal flushing from this region comes in contact with widespread estuarine and mud flat areas and areas used for sport fisheries.

The Naval station at Treasure Island is located on the island which lies in San Francisco Bay, midway between San Francisco and Oakland, and is connected to both cities by bridge. The maximum current at the Naval station is 3.1 knots.

There are 24 shore line miles of nearby industrial facilities including yacht harbors and major shipping facilities. Tidal flushing from this region comes in contact with widespread mud flat areas and areas used for sport fisheries.

The Naval Air Station at Alameda is located on the eastern shore of San Francisco Bay due west of the city of Alameda at the entrance to Oakland Harbor, and is immediately south of the U.S. Naval Supply Center. This projection of land is almost entirely surrounded by water. The maximum current off the air station is 1.8 knots. There are 20 shore line miles of nearby industrial facilities including major shipping facilities and yacht harbors. Tidal flushing from this region comes in contact with widespread mud flat areas and areas used for sport fisheries.

The Naval Fuel Depot at Point Molate is located on the northeastern shore of San Francisco Bay on a projection of land northwest of the city of Richmond. The maximum current at the fuel depot is 1.8 knots. There are 10 shore line miles of industrial facilities including major shipping facilities and yacht harbors. Tidal flushing from this region comes in contact with widespread mud flat areas and areas used for sport fisheries.

Long Beach Harbor is located on the Pacific Coast on the southern shore of the city of Los Angeles within the breakwater projected portion of San Pedro Bay. It is joined on the west by the Los Angeles Harbor. The inner and middle of these two harbors consist of a maze of interconnected basins and channels. These two harbors cover an area of 13.8 square nautical miles and have 28 shore line miles of industrial or military facilities. It is the largest port on the Pacific Coast in terms of tonnage handled, and there are numerous small craft moorages located on the inner basins and channels. The average mean and maximum tides are 3.8 and 9 ft. The prevailing winds are west and average 6.3 knots. The high winds are also from the west and rarely exceed 54 knots. The mean sea temperature is 61.8 °F and the mean air temperature is 61.9 °F. The tidal currents follow the channels and rarely exceed one knot. Annual precipitation is 12.6 in.

The principle U.S. Naval facilities in the Long Beach Harbor are the Naval Shipyard and the Naval Station. Both are located on the inner harbor on the southern side of Terminal Island, and are used as an operating base by the U.S. Fleet. Serving much of this fleet is the U.S. Naval Fuel Depot at San Pedro.

Oil spillage in the Long Beach Harbor could migrate to almost any point on the two harbor complex depending on

environmental conditions such as wind and surface-currents. Although reasonably well enclosed and easier to contain than most harbors, oil spillage in the Long Beach Harbor, on the ebb tide, could migrate into San Pedro Bay where prevailing winds might drive it to the shore at the city of Long Beach and down the coast line of California. Figure A-12 shows the geography of this area.

San Diego Bay is located on the Pacific Coast on the southern end of the state of California. Figure A-7 shows important geographic and physical features. It is a well sheltered body of water covering an area of 14 square nautical miles and having a tidal prism of 0.0095 cubic nautical miles. The mean air temperature is 63.2 °F. The mean sea temperature is 61.4 °F. The 28 nautical miles of shore line include recreational, industrial and military facilities. Average mean and maximum tides are 4.1 and 9 ft. Prevailing winds are west northwest and average 5.6 knots. The high winds are from the southeast and rarely exceed 44 knots. Annual precipitation is 10.6 in.

All of the Naval facilities located on San Diego Bay are on open faces of the main body of water. Oil spillage at these facilities can migrate to any point on the entire Bay depending on environmental conditions such as wind and surface currents. The currents generally follow the contour of the crescent-shaped Bay and have a maximum velocity of 3.0 knots.

The following U.S. Naval facilities are located on San Diego Bay: Naval Air Station - North Island, Naval Fuel Depot - Point Loma, Naval Submarine Facilities - Point Loma, Naval Supply Center - San Diego, Naval Berthing - North Island, Naval Repair Station and Naval Amphibious Base, Naval Training Center.

Extensive small boat moorages, for both recreational and commercial craft, are located in the vicinity of Shelter Island on the northwest shore of the Bay. Major shipping facilities are located on the northeast shore. The Coronado Yacht Club is located on Glorietta Bay due south of the city of Coronado, opening north-westward into San Diego Bay.

There are several salt ponds located on the southern end of the Bay.

TABLE A-1. Environmental and Physical Features of Ports

	Area, square naut mi	Mean Tide, ft	Max Tide, ft	Max Current, knots	Prevailing Winds, knots	High Winds, knots	Precip, in.	Mean Sea Temp, °F	Mean Air Temp, °F	Shoreline, naut mi	Tidal Prism, cu naut mi
Puget Sound	767	8	15	5.0	10 S	61 S	40	50	50	1157	1.27
Naval Shipyard--Bremerton		8.0	14.7	1.5	10 S	60 S	40	50	50		
Naval Fuel Depot--Manchester		7.6	14.8	1.2	10 S	60 S	4C	50	50		
Naval Supply Center--Seattle		7.6	14.7	0.5	8.3 SSW	48 SSW	38.9	50	51.1		
Naval Torpedo Station--Keyport		8.0	15	1.1	10 S	60 S	40	50	50		
Naval Ammunition Depot--Bangor		7.9	14.9	1.0	10 S	60 S	38	50	50		
San Francisco Bay	309	4	9	6.5	9	54 SW	18.7	55.6	56.0	160	0.26
Naval Shipyard--Mare Island		5	10	2.4	9 WNW	54 SW	18.7	55.6	56.0		
Naval Shipyard--Hunters Point		4	9	1.8	9 WNW	54 SW	18.7	55.6	56.0		
Naval Station--Treasure Island		4	9	3.1	9 WNW	54 SW	18.7	55.6	56.0		
Naval Air Station--Alemeda		4	9	1.8	9 WNW	54 SW	18.7	55.6	56.0		
Naval Fuel Depot--Point Molate		4	9	1.8	9 WNW	54 SW	18.7	55.6	56.0		
San Pedro Bay	13.8	3.8	9	1.0	6.3 W	54 W	12.6	61.8	61.9		
Naval Shipyard--Long Beach		3.8	9	1.0	6.3 W	54 W	12.6	61.8	61.9		
Naval Station--Long Beach		3.8	9	1.0	6.3 W	54 W	12.6	61.8	61.9		
Naval Fuel Depot--San Pedro		3.8	9	1.0	6.3 W	54 W	12.6	61.8	61.9		
San Diego Bay	14	4.1	9	3.0	5.4 WNW	44 SE	10.4	61.4	63.2	28	0.0095
Naval Station--San Diego		4.2	10	2.5	5.4 WNW	44 SE	10.4	61.4	63.2		
Naval Fuel Depot--Point Loma		4.1	9	3.0	5.4 WNW	44 SE	10.4	61.4	63.2		
Pearl Harbor		1	2	0.5	10 ENE	58 SW	21.9	78.1	75.9		
Naval Base--Pearl Harbor		1	2	0.5	10 ENE	58 SW	21.9	78.1	75.9		

TABLE A-1. (Contd)

	Mean Tide, ft	Maximum Current, knots	Prevailing Wind, knots	Direction	High Winds, knots	Direction	Precip, in.	Mean Sea Temp, °F	Mean Air Temp, °F
Massachusetts Bay	9.5		11.4	SW	56	NNW	42.77	50.3	51.4
Naval Shipyard--Boston	9.5	1.0	11.4	SW	56	NNW	42.77	50.3	51.4
Narragansett Bay	4.6		9.7	SW			42	51.8	50.1
Naval Base--Narragansett (Newport)	4.6	[illegible]	9.7	SW		NW	42	51.8	50.1
Naval Air Station--Quonset Point	4.6	0.6	9.7	SW		NW	42	51.8	50.1
Submarine Base--New London	2.6	0.8					41	59.6	50.2
Delaware Bay	2.9		8.3	WSW	63	NW	42.48	57.4	53.5
Naval Shipyard--Philadelphia	2.9	2.4	8.3	WSW	63	NW	42.48	57.4	53.5
Naval Shipyard--Portsmouth, Virginia	1.9	4.0	9.0	SW	68	S	45	60	59.7
Naval Supply Center--Norfolk, Virginia	1.9	0.6	9.0	SW	68	S	44.94	60	59.7
Naval Amphibious Base--Little Creek	2.8	1.0	9.0	SW	68	S	45	60	59.7
Charleston Harbor	2.6	2.0	7.7	NE			49.16	68.0	65.0
Naval Shipyard--Charleston	2.6	2.0	7.7	NE			49.16	68.0	65.0
Naval Station--Charleston	2.6	2.0	7.7	NE			49.16	68.0	65.0
Naval Fuel Depot--Charleston	2.6	2.0	7.7	NE			49.16	68.0	65.0
Naval Fuel Depot--Jacksonville	1.2	1.0	7.6	NW	63	E	53.36	73.6	69.5
Naval Station--Mayport	1.2	3.1	7.6	NW	63	E	53	71.2	68.0
Naval Station--Key West	1.3	1.5	9.9	ESE	106	NW	39.99	79.4	76.8
Naval Station--San Juan, Puerto Rico	1.0	1.0	7.3	ENE	70	NE	64.21	81.0	78.0

TABLE A-2. Nearby Features

	Recreational Beaches	Mud Flats	Kelp Beds	Estuaries	Boat Marinas	Industrial Facilities	Sport Fisheries	Commercial Fisheries	Commercial Shellfish
Puget Sound									
Naval Shipyard--Bremerton	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No
Naval Fuel Depot--Manchester	Yes	No	Yes	No	No	Yes	Yes	No	No
Naval Supply Center--Seattle	Yes	No	No	No	No	Yes	Yes	No	No
Naval Torpedo Station--Keyport	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Naval Ammunition Depot--Bangor	Yes	No	Yes	No	Yes	No	Yes	No	Yes
San Francisco Bay									
Naval Shipyard--Mare Island	No	Yes	No	Yes	Yes	Yes	Yes	No	No
Naval Shipyard--Hunters Point	No	Yes	No	Yes	Yes	Yes	Yes	No	No
Naval Station--Treasure Island	No	Yes	No	Yes	Yes	Yes	Yes	No	No
Naval Air Station--Alemeda	No	Yes	No	Yes	Yes	Yes	Yes	No	No
Naval Fuel Depot--Point Molate	No	Yes	No	Yes	Yes	Yes	Yes	No	No
San Pedro Bay									
Naval Shipyard--Long Beach	No	No	No	No	Yes	Yes	Yes	No	No
Naval Station--Long Beach	No	No	No	No	Yes	Yes	Yes	No	No
Naval Fuel Depot--San Pedro	Yes	No	Yes	No	Yes	Yes	Yes	No	No
San Diego Bay									
Naval Station--San Diego	Yes	No	No	Yes	Yes	Yes	Yes	No	No
Naval Fuel Depot--Point Loma	Yes	No	Yes	No	Yes	Yes	Yes	No	No
Pearl Harbor									
Naval Base--Pearl Harbor	Yes						Yes		

TABLE A-3. U.S. Weather Bureau Decennial Census

	Percentage/Accumulated Percentage of Wind Speed, mph										
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 over	Calm	Average
Puget Sound (Seattle-Tacoma Airport, 1951-1960)	13/13	16/29	35/64	26/90	8/98	2/100	±	±	±	10	11
San Francisco (San Francisco International Airport, 1951-60)	16/16	21/37	26/63	22/85	11/96	3/99	±	±	±	8	10
San Diego (Lindbergh Field, 1951-60)	28/28	38/66	28/94	6/100	±	±	±			6	6
Pearl Harbor (Honolulu International Airport, 1951-60)	9/9	17/26	27/53	32/85	12/97	2/99	±	±	±	1	12
Boston (Logan International Airport, 1951-60)	3/3	12/15	33/48	35/83	12/95	4/99	1/100	±	±	1	13
Charleston, So. Carolina (Municipal Airport, 1951-60)	12/12	28/40	35/75	19/94	4/98	1/99	1/100	±		7	9
Norfolk, Virginia (Municipal Airport, 1951-60)	14/14	23/37	30/67	25/92	6/98	1/99	2/101	±	±	2	10
San Juan, Puerto Rico	15/15	28/43	27/70	25/95	4/99	±	±	±	±	9	9.1

	Percentage/Accumulated Percentage of Wind Speed, knots							
	0-3	4-10	11-21	22-27	28-40	41 over	Calm	Average
Long Beach, California (Municipal Airport, 1947-57)	48/48	45/93	6/99	0.2/99.2	0.0	0.0	31	4

	Percentage/Accumulated Percentage of Wind Speed, knots						
	0-2	3-7	8-12	13-20	21-40	40 over	Calm
Quonset Point, Rhode Island	7/7	18/25	27/52	32/84	15/99	1/100	3

Accumulated Percentage Frequency for ≤ Upper Parameter of Range of Wind Velocities

0.0 < ± <0.5 mph
0.0 < .0 <0.05 knots

TABLE A-4. Wave Height Prediction for 90% Probability

Area and Port	Max Wind Vel 90% of Time, mph	Prev Wind Direction	Fetch, N Mi	Avg Depth of Water, ft	Max Significant Wave Height, ft	Min Wave Length, ft	Average Wave Length, ft
Puget Sound	≤18	SSW					
Naval Shipyard--Bremerton			2.2	39	1.15	8.05	23
Naval Fuel Depot--Manchester			2.2	42	1.15	8.05	23
Naval Supply Center--Seattle			14.2	180	2.60	18.2	48
Naval Torpedo Station--Keyport			2.7	20	1.22	8.55	24
Naval Ammunition Depot--Bangor			3.3	130	1.37	9.6	27
San Francisco Bay	≤20	WNW					
Naval Shipyard--Mare Island			0.5	25	0.72	5.04	15
Naval Shipyard--Hunters Point			2.0	30	1.25	8.75	25
Naval Station--Treasure Island			5.0	60	0.69	4.83	14
Naval Air Station--Alemeda			4.0	30	1.63	11.4	31
Naval Fuel Depot--Point Molate			4.0	40	1.63	11.4	31
San Pedro Bay	≤9	W					
Naval Shipyard--Long Beach			0.8	45	0.39	2.73	8
Naval Fuel Depot--San Pedro			0.5	40	0.32	2.24	7
San Diego Bay	≤11	WNW					
Naval Station--San Diego			2.0	30	0.59	4.13	12
Naval Fuel Depot--Point Loma			0.2	30	0.61	4.27	13
Massachusetts Bay	≤21	SW					
Naval Shipyard--Boston			0.5	35	0.77	5.40	15
Charleston Harbor	<16	NE					
Naval Shipyard--Charleston			0.8	38	0.59	4.13	12
Naval Station--Charleston			0.8	38	0.59	4.13	12
Naval Fuel Depot--Charleston			0.8	38	0.59	4.13	12
Norfolk, Virginia	≤18	SW					
Naval Shipyard--Norfolk			0.3	38	0.57	4.0	12
Naval Supply Center--Norfolk			2.0	41	1.09	7.62	21
Hawaii	≤20	ENE					
Naval Shipyard--Pearl Harbor			2.5	40	1.36	9.52	26

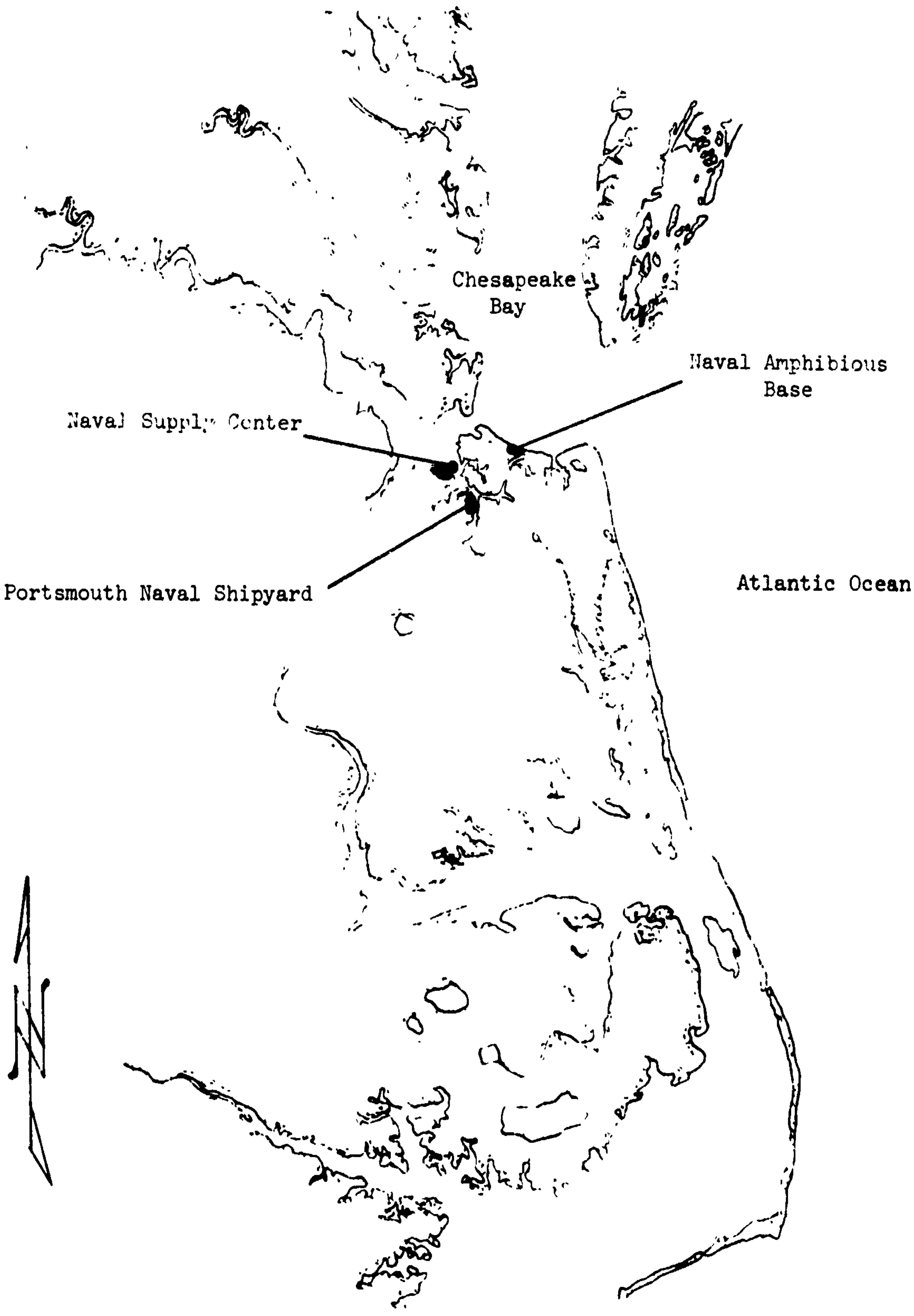

FIGURE A-1. Chesapeake Bay Geography

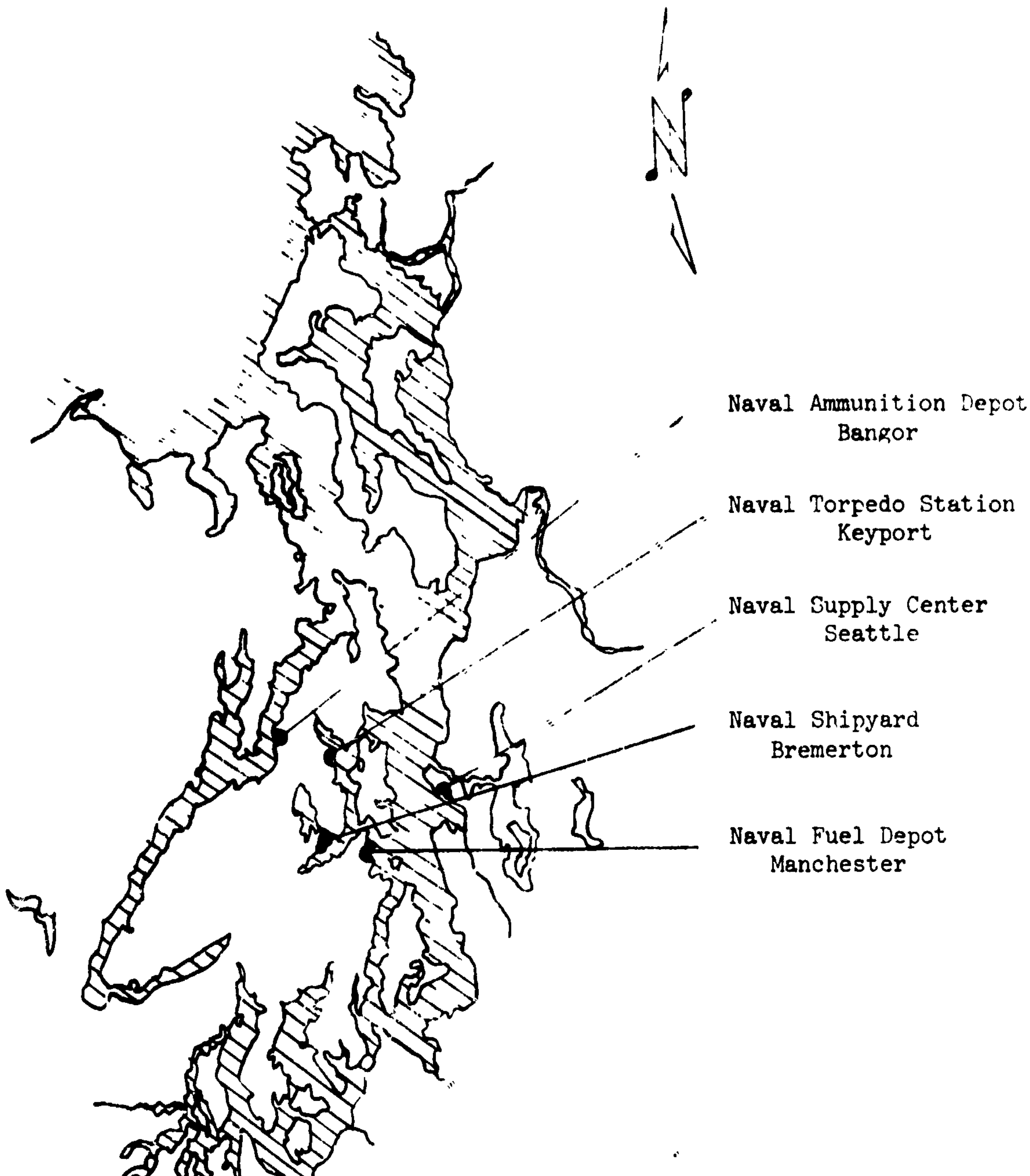

FIGURE A-2. Puget Sound Geography

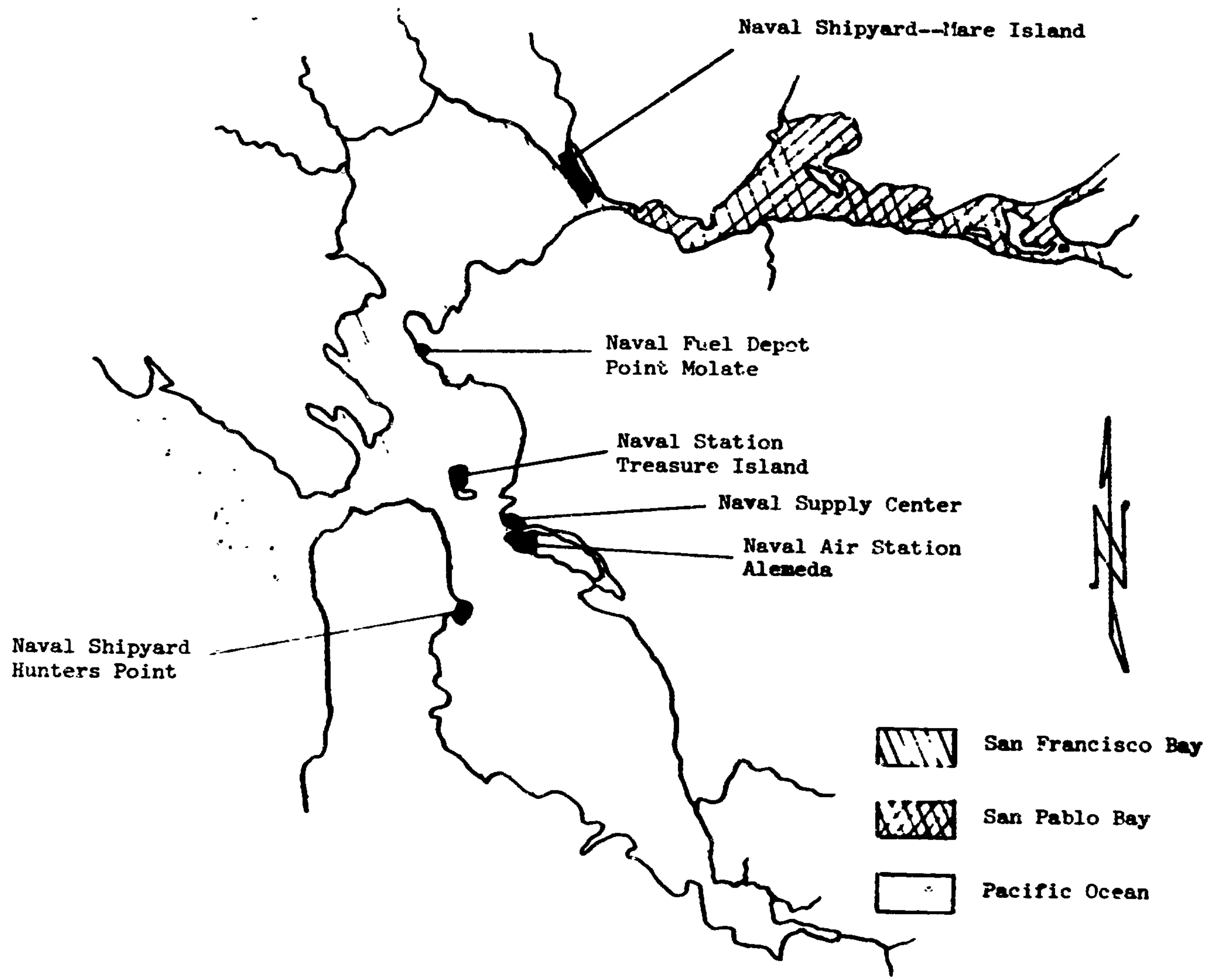

FIGURE A-3. *San Francisco Bay Geography*

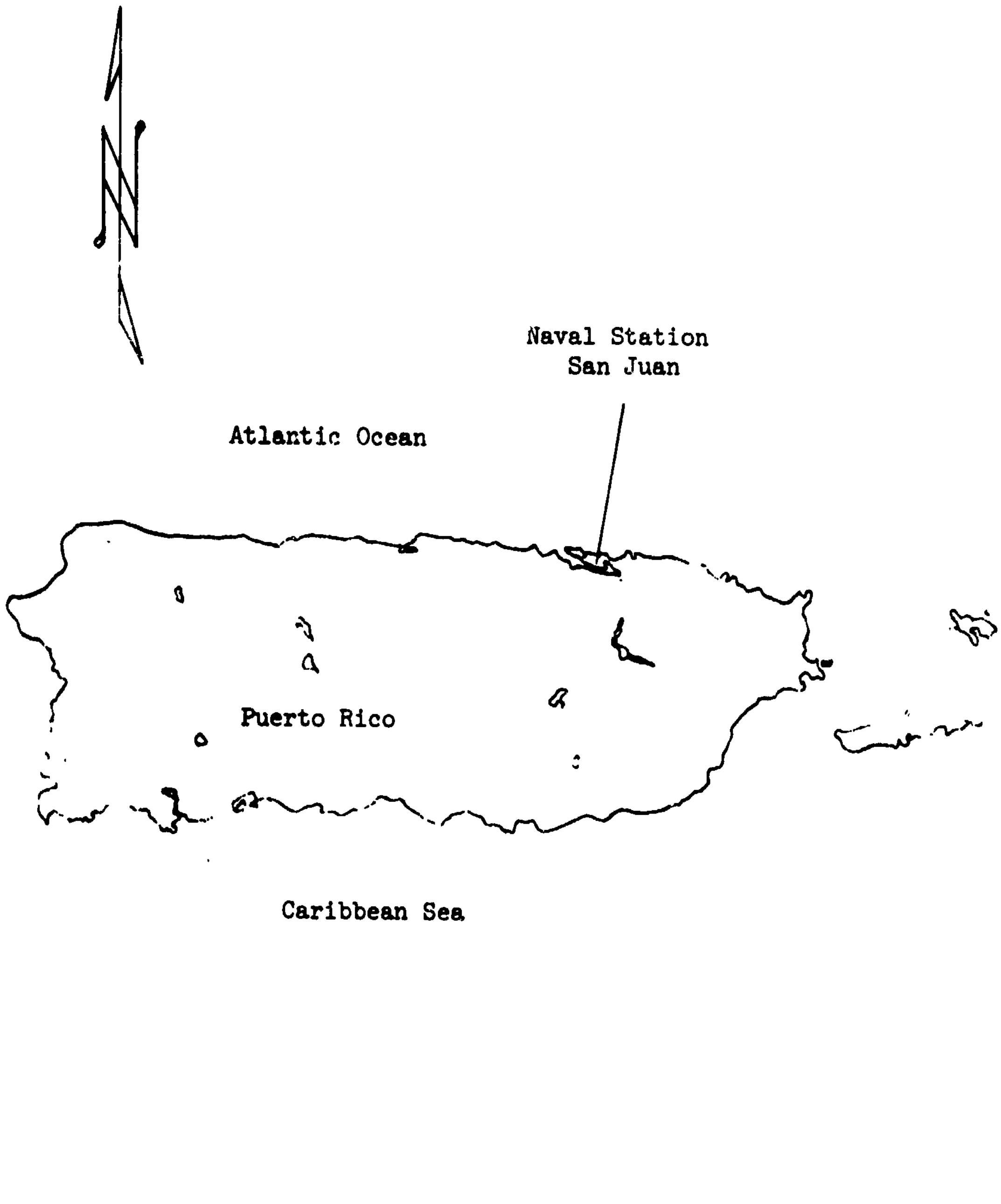

FIGURE A-4. *Puerto Rico Geography*

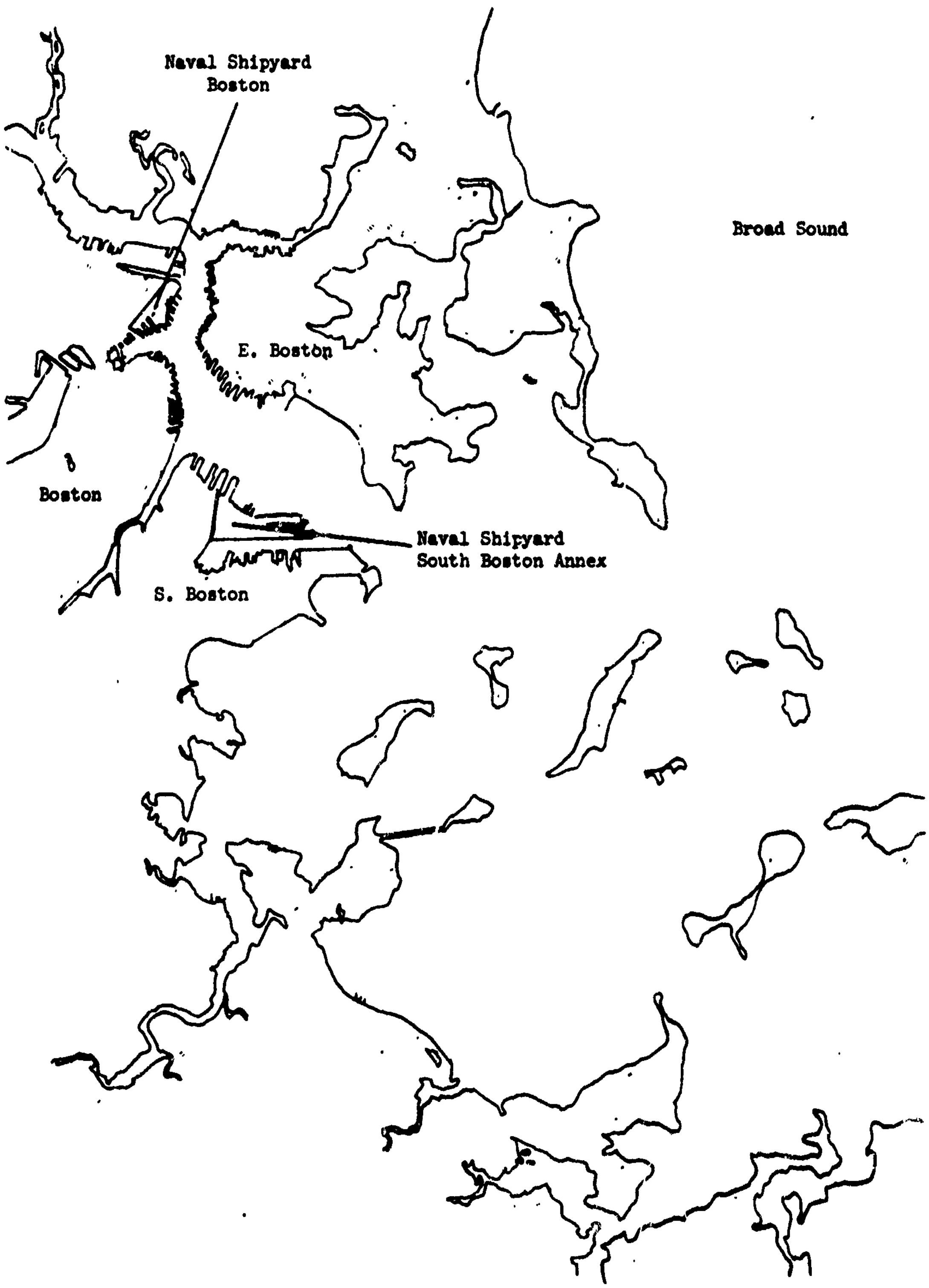

FIGURE A-5. Boston Harbor Geography

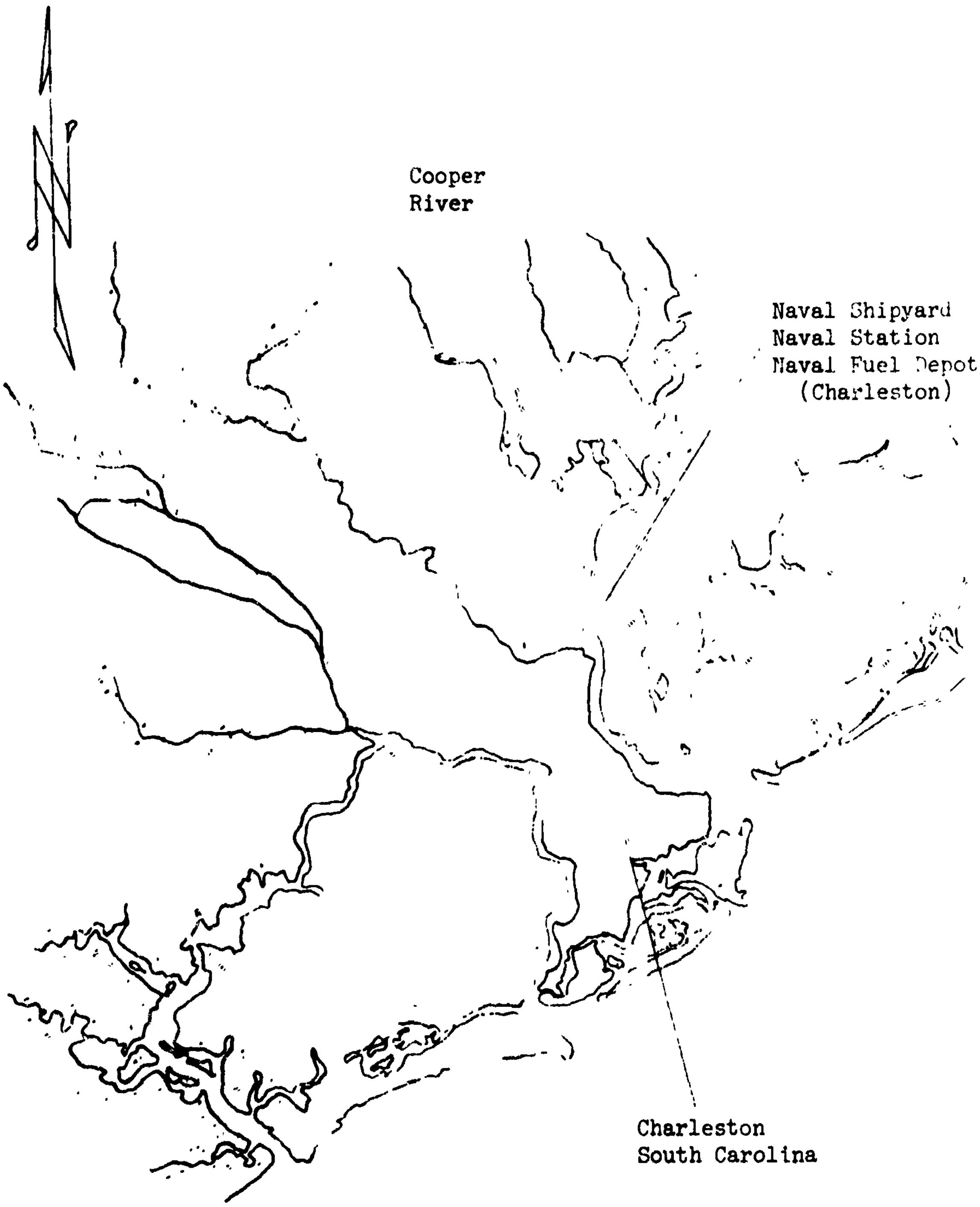

FIGURE A-6. Port of Charleston Geography

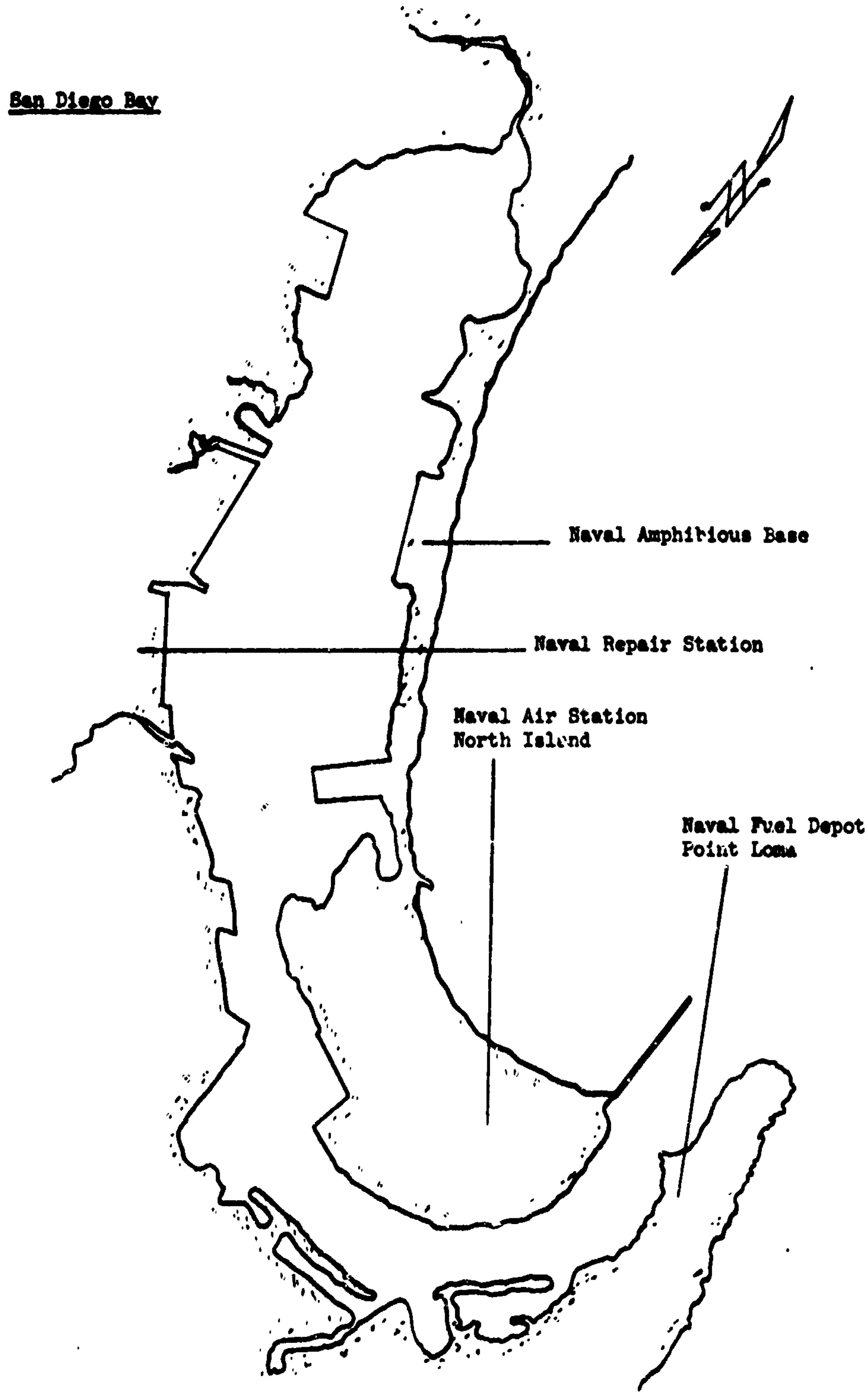

FIGURE A-7. *San Diego Bay Geography*

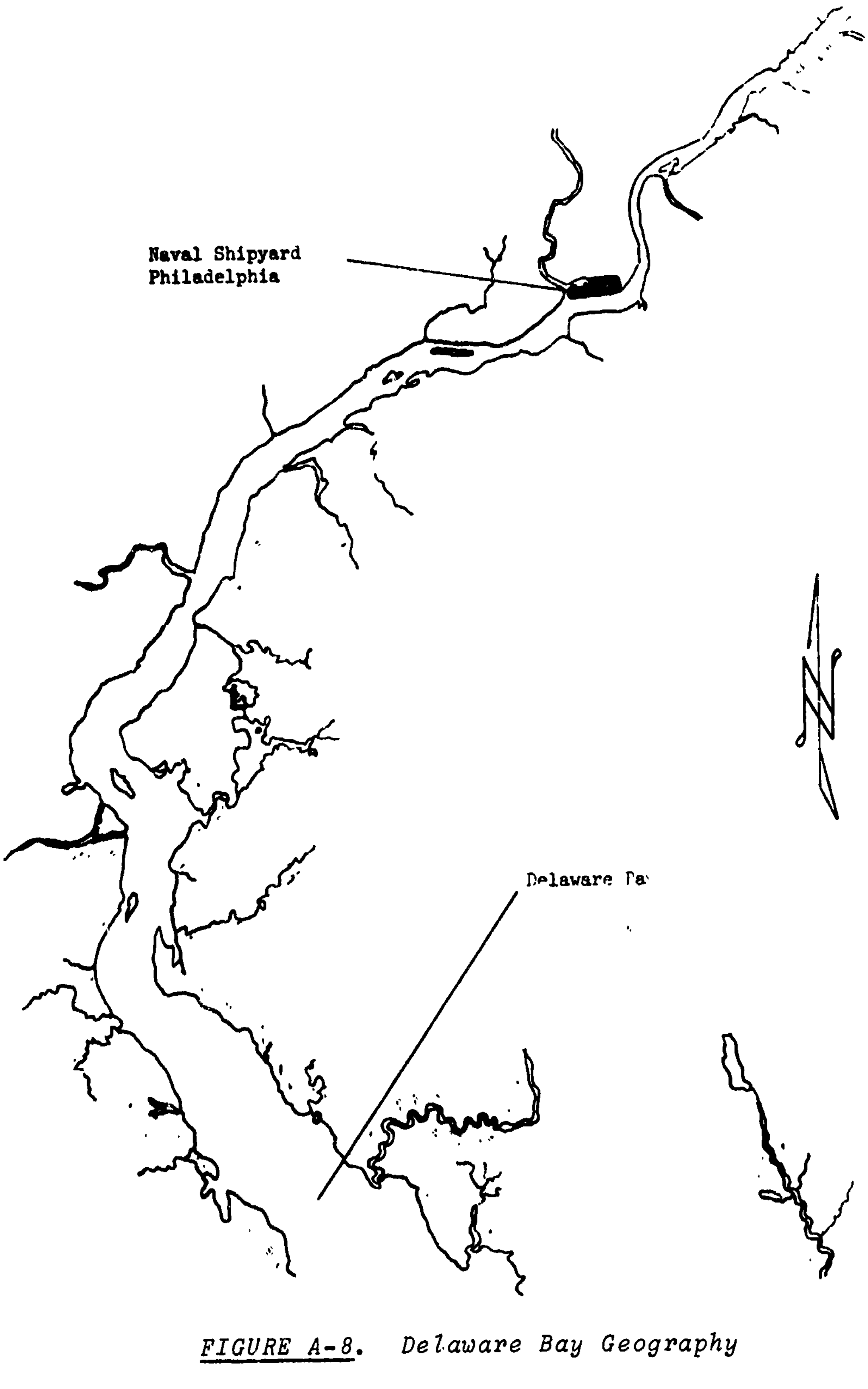

FIGURE A-8. Delaware Bay Geography

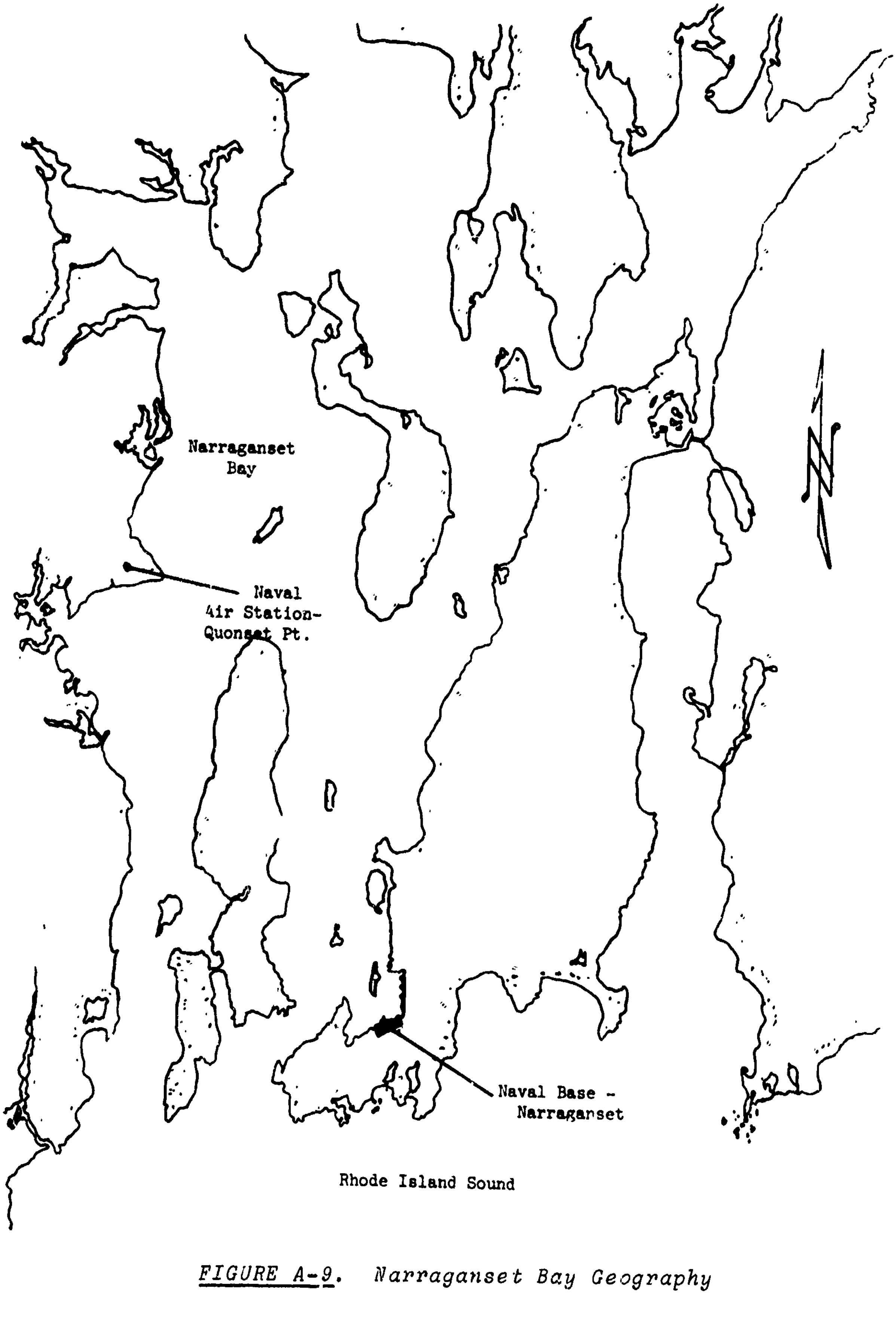

FIGURE A-9. Narraganset Bay Geography

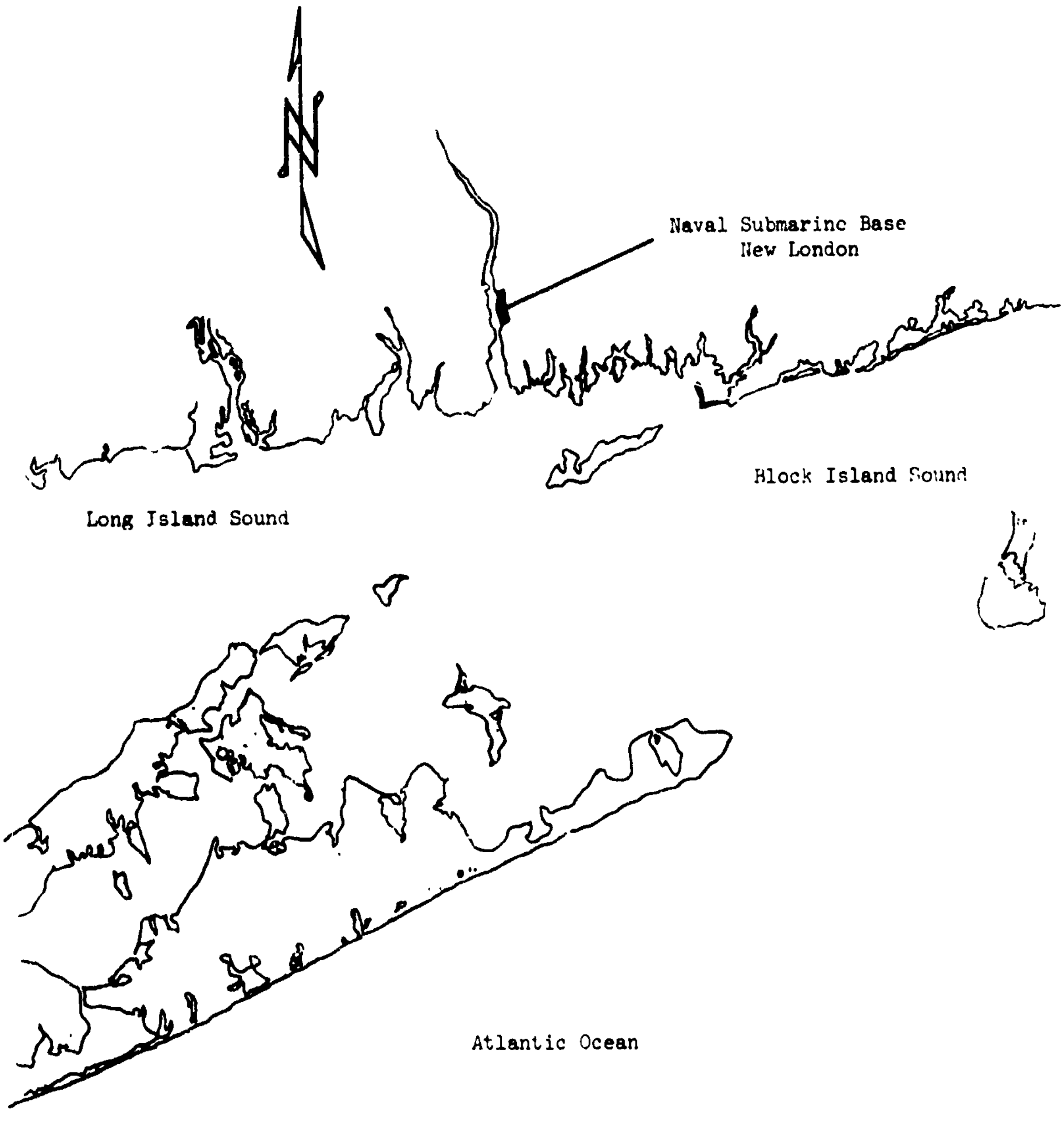

FIGURE A-10. *Long Island Sound Geography*

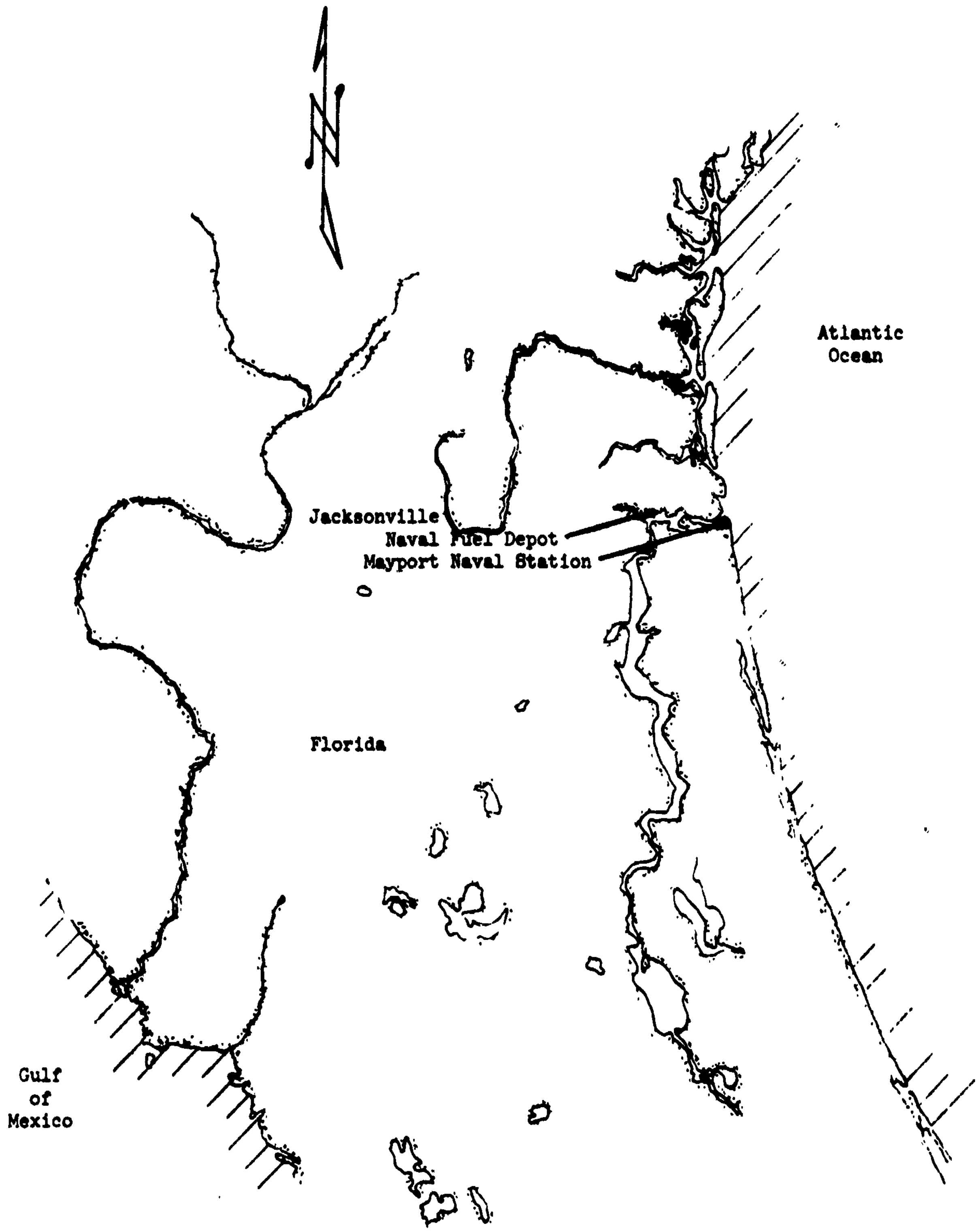

FIGURE A-11. Port of Jacksonville Geography

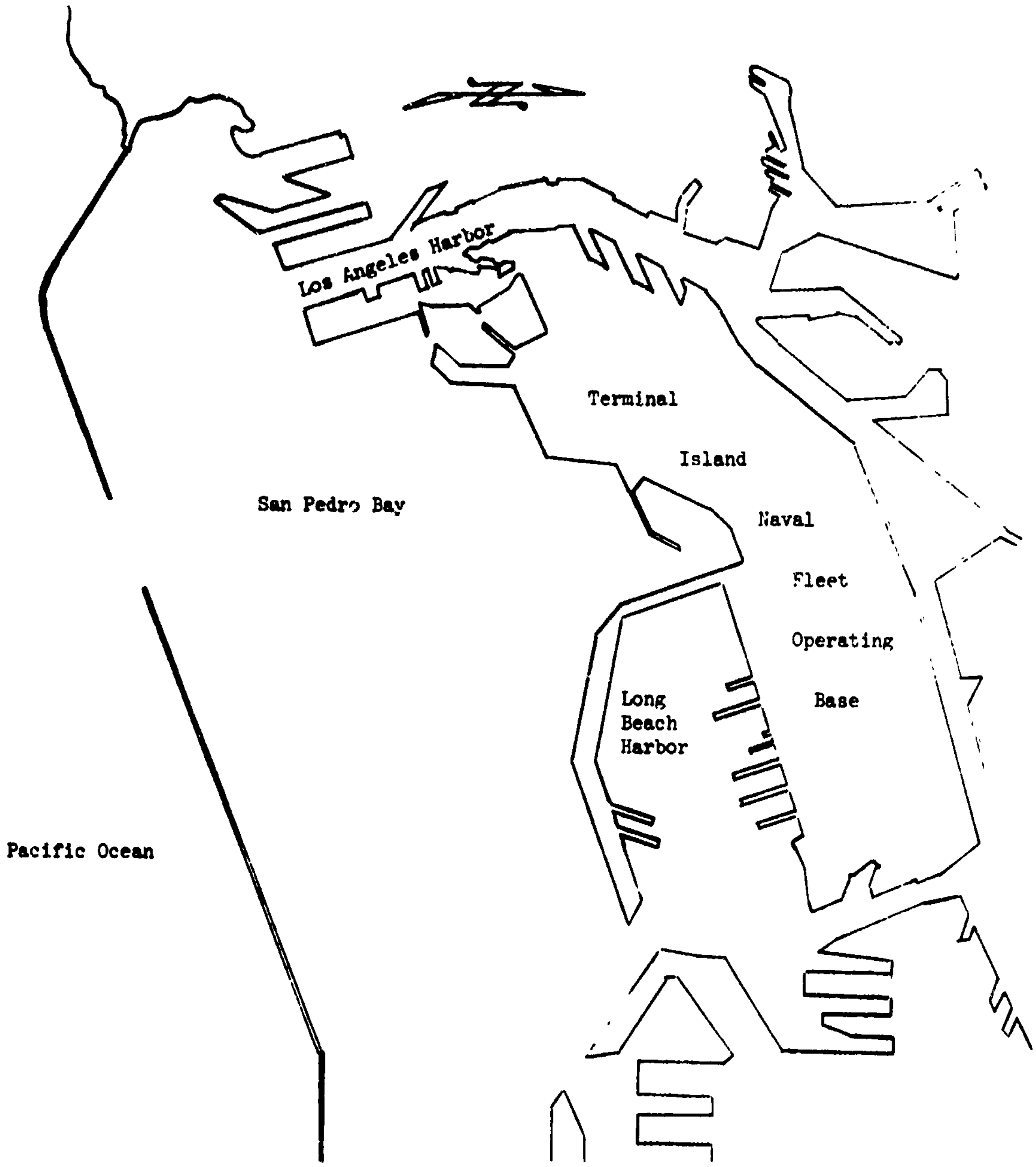

FIGURE A-12. *San Pedro Bay Geography*

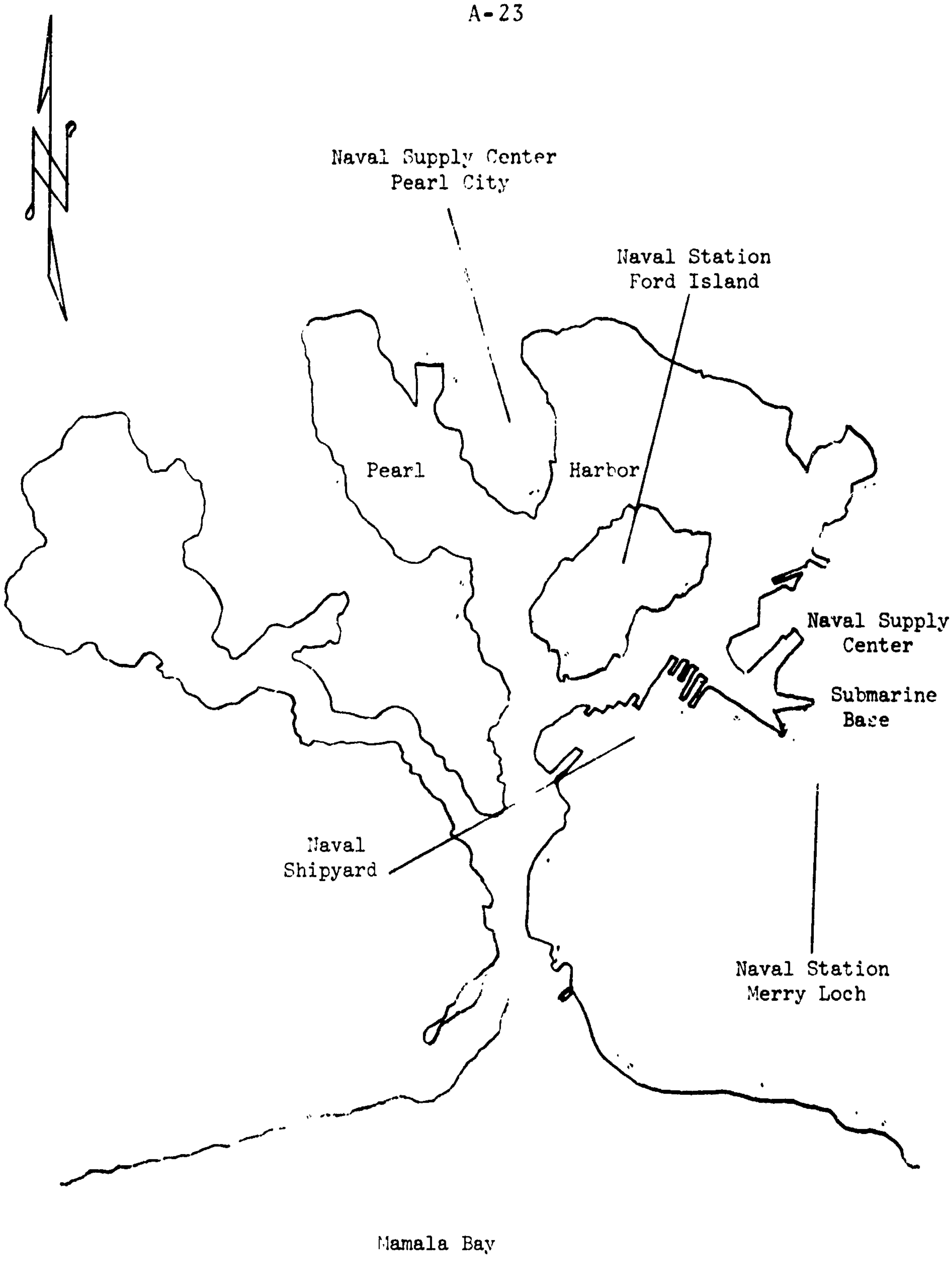

FIGURE A-13. *Pearl Harbor Geography*

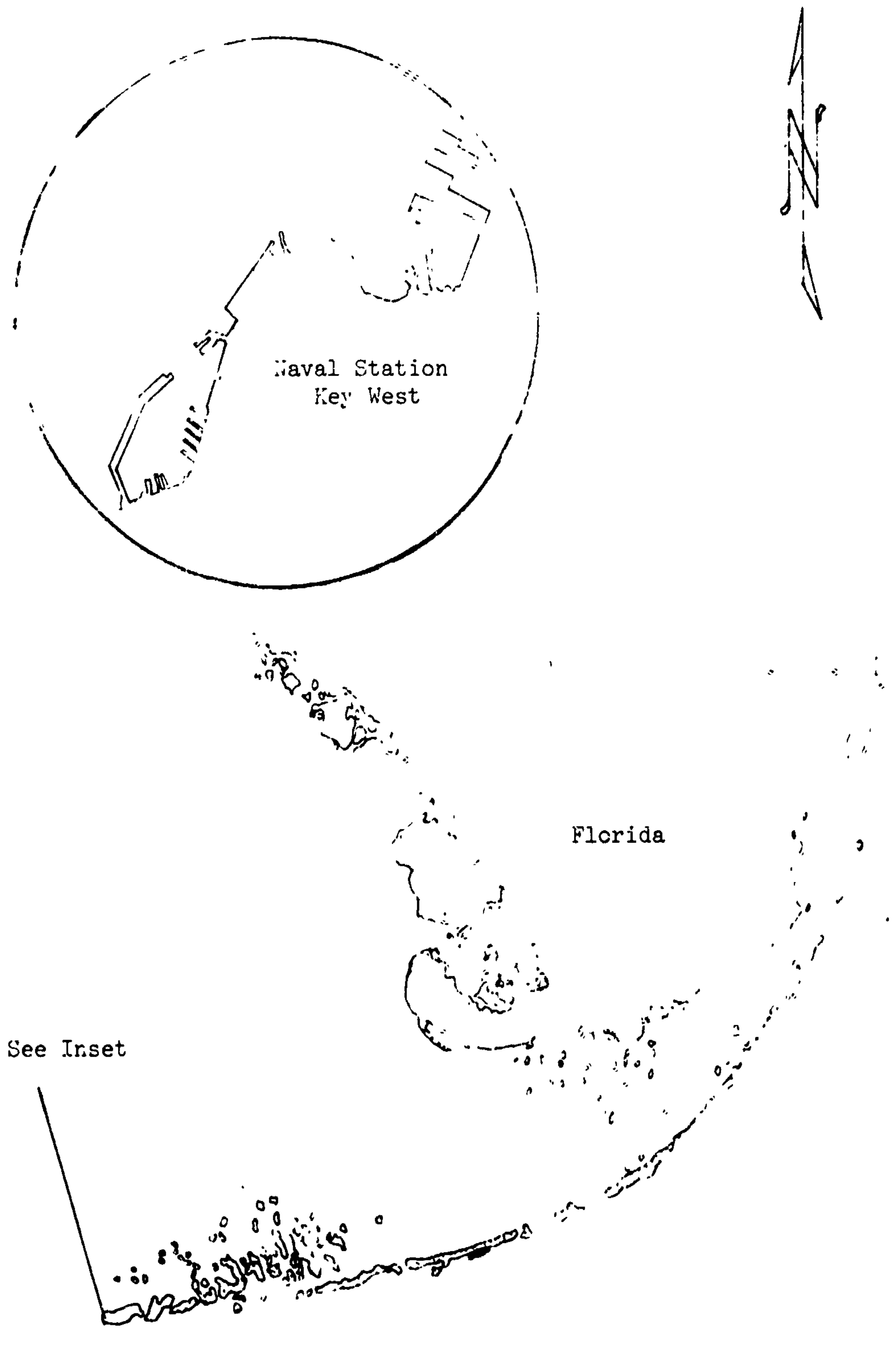

FIGURE A-14. *Key West Geography*

APPENDIX B

PROCUREMENT DATA AND PERFORMANCE NOTES
ON EQUIPMENT AND MATERIALS

I. CONTAINMENT DEVICES

1. CORK FLOAT BOOMS (COMMERCIAL)(1)

Cork float booms (Reference 1) are constructed from a series of cork discs 6 in. in diameter by 2 in. thick and 3 in. in diameter by 1 in. thick, strung alternately on a 3/8 in. diameter polyvinyl coated steel or bronze cable. The cork floats are enclosed in a polyvinyl or canvas cover which may or may not be perforated. These booms are available in 50-ft sections and are normally unskirted. The inherent flexibility of this configuration permits the boom to follow the water profile extremely well. However, without skirts, underslip of accumulated oil can impose a severe problem and, therefore, these booms should not be employed when surface currents or moderate winds are prevalent. Cork float booms cost about $6 per foot. They are durable, easily handled and cleaned, and readily deployed, particularly when stored on reels. The boom is available from a number of vendors. A similar makeshift boom (used at Norfolk) employs granular cork bits surrounded by a 6 in. diameter neoprene fabric covering.

2. GALVAING BOOM (COMMERCIAL)

This boom consists of rigid floats which are inserted into plastic-coated fabric and attached to PVC-coated flexible asbestos panels. The boom sections (16 to 20 ft) are formed by adding several individual units 3 to 4 ft long to provide flexibility. For extended lengths, connections are provided at the end of each section. Krypton signals are available to provide a warning light up to 75 ft away at night.

The boom is available in three main types: (1) the PB type flexible emergency barrier comes in 20 ft sections with floatation provided by polyurethane-filled floats. Lead ballast of 1.3 lb/ft is fastened to the bottom of the 1/4 in. Navy plywood skirts. Additional ballast is also available for tidal current or towing applications. The maximum dammed height is 8 in. with a working depth of 6 in. (2) A fire control barrier of similar construction employs fireproof floats and a skirt of asbestos cloth coated with PVC and strengthened with mosquito net mesh cloth. (3) The long-skirted unballasted barrier consists of units identical to the PB barrier with the addition of a neoprene-treated nylon cloth skirt. A galvanized steel chain is threaded through the lower hem of the skirt to maintain vertical stability. The skirt also contains plywood battens with lead weight ballast attached.

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1. *A. L. Scott and S. E. Gifford. "Removal of Oil from Harbor Waters," Naval Civil Engineering Laboratory Technical Note N-964, February 1968.*

The approximate prices of the three types are as follows:

PB type barrier $13.60/ft ($16/ft with krypton signals)
Fire control barrier $16/ft ($18.50/ft with krypton signals)
Long-skirted barriers $14.80/ft ($17.25/ft with krypton signals)

3. "SEA CURTAIN" (COMMERCIAL)

This boom consist of a cylindrical floatation section, either foam-filled or air-inflatable with a skirt suspended below. The foam blocks are in short sections for flexibility. Ballast is provided by a chain running through the bottom of the skirt. This boom is manufactured by Kepner Plastics Fabricators, Inc. The fittings at the end of each section are identical to those of the "Slick Bar" and, therefore, these booms may be joined together. The deep skirt permits utilization for dragging or sweeping operations.

The boom is available in four basic sizes:

a. A heavy duty ocean service foam-filled float 20 in. in diameter with a 30 in. skirt extending below. Approximate price is $10 to $15/ft.*
b. A heavy duty harbor and channel service with foam-filled float. The float is 12 in. in diameter with an 11 in. skirt extending below. The approximate price is $6 to $9/ft.*
c. An emergency containment boom with an inflatable float. The inflated portion is 19 in. in diameter with a 32 in. skirt extending below. The approximate price is $4 to $6/ft.*
d. A light duty emergency containment boom with inflatable float. The inflatable section is 12 in. in diameter with an 11 in. skirt extending below. Approximate price is $2 to $4/ft.*

The length of the extended skirt makes these booms particularly applicable in areas where surface currents are appreciable.

4. "SEA FENCE" (COMMERCIAL)

This barrier consists of rigid vertical barriers of aluminum sheets held together by steel cable and provided with foamed plastic material for floatation and neoprene joints to provide a flexible seal between panels. It is fireproof and capable of storage on reels. This boom is produced by the Aluminum Company of America (ALCOA) and will become available in several sizes. A prototype model was tested but not employed at Santa Barbara.

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* *Based on 5000 ft length FOB Factory.*

5. "SLICK BAR" (COMMERCIAL)

This boom is produced by Neirad Industries, Inc. and consists of a flexible plastic fin (skirt) supported by foam plastic floats. The floats are 3 ft long with a 12 in. space between each to permit folding and connectors. The boom is lightweight and easily handled. The fin consists of 0.030-in thick polyethelene with small lead weights clipped to the bottom. It may be produced in any continuous length up to 10,000 ft.

The boom is accordion-folded for storage in 10 ft folds. Prices range from $2.25/ft for models with a 6 in. fin and 3 in. float to $8.30/ft for those with a 24 in. fin and 6 in. float. Additional weights can be added for dragging or skimming operations. (See Appendix D.)

6. SOS BOOM (COMMERCIAL)

This boom is manufactured in Sweden and distributed in the U. S. by Surface Separator Systems, Inc. It is made in two styles: A permanent boom of glass-fiber-reinforced polyester and an inflatable emergency boom. The permanent boom is manufactured in 10 ft lengths and consists of 7 in. diameter tubes of fiber glass filled with urethane foam. A nylon reinforced PVC coated skirt provides an 18 in. draft. Chain ballast is fitted into the hem of the skirt. Couplings are provided to fasten sections. The price is approximately $5.50/ft.

The inflatable emergency boom is manufactured in 80 ft sections of PVC air inflated tubing. A 14 in. skirt is provided with chain ballast along the hem. The chain is also used for towing. The 80 ft sections have a unit weight of 0.3 lb/ft and cost $1.40/ft.

7. "SPILL GUARD" (COMMERCIAL)

This boom is manufactured by Johns-Manville and is constructed of asbestos sheet material. Floatation is provided by foam floatation cells attached to both sides of the sheet. Fin ballast is attached at the bottom of the sheet. The boom is furnished in 100 ft lengths (10 hinged sections 10 ft long). It is accordion-folded for storage.

Two models are available: (1) 4 in. of barrier above the water surface and 11 in. below, costing approximately $7.50/ft, and (2) 12 in. above the water and 24 in. below, costing approximately $20/ft. The larger model is suitable for dragging or sweeping operations. The smaller version weighs approximately 3 lb/ft and the larger approximately 9 lb/ft.

8. "T-T OIL" (COMMERCIAL)

The T-T boom is manufactured by the Trygve Thune A/S of Norway and distributed by Hurum Shipping and Trading Company Ltd. Montreal, Canada. The boom is constructed of a nylon skirt with PVC plastic pressed into the cloth on both sides. Foam plastic floats are attached to both sides of the boom and lead weights are attached at the bottom. Aluminum battens sewn into the sheet provided vertical stability. The boom is stored by folding accordian-wise and the same folding can be used to reduce the boom enclosure area.

The boom is fabricated in sections 164 ft long by 3 ft high (1 foot of free board) and has a unit weight of 1.5 lb/ft.

9. WARNE BOOM (COMMERCIAL)(1)

Warne boom is constructed of thin fabric-reinforced synthetic rubber. It consists of an air inflatable floatation tube and skirt with a chain pocket at the bottom. The floatation tube can also be filled with short sections of synthetic foam and is available in either 8 or 16 in. diameters. The skirt is available in 18 or 22 in. widths. Foam filled booms are recommended for permanent installations.

The inflatable version can be used as a rising and sinking boom to permit crossing by ships. This is accomplished by inflating or deflating the middle sections. The inflatable boom is pressurized to 40 psi. The price of the inflatable boom varies from $16.50 to $25/ft, depending on size and capability. The foam filled models cost from $23.50 to $47/ft. The boom can be assembled from individual 25 or 50 ft sections. The heavy weight of this boom makes it hard to tow or deploy rapidly. The boom is manufactured by William Warne and Company Ltd. of England and distributed by Surface Separator Systems, Inc. (See Appendix D.)

10. FIRE HOSE BOOM(1)

Make-shift air inflated fire hose is employed in many port and harbor areas throughout the United States for oil spill containment in relatively calm waters. The metal hose couplings are removed and replaced with plastic or aluminum inserts to join succeeding sections. Air valve fittings must be provided in the ends. They are easily towed and can be rolled up for compact storage when deflated. The relative stiffness permits oil to wash over and under when the water surface is rough or choppy. The main advantage of these booms is the low price, particularly when discarded fire hose is employed.

11. WOODEN TIMBER BOOMS

Make-shift booms can be fabricated by joining short sections of wooden timbers together and wrapping the joints with canvas to prevent the oil leakage. This type of boom can be fabricated from any available wooden sections and in some cases satisfactory booms have been constructed from used telephone poles joined by steel cable. The one disadvantage is a lack of sufficient flexibility unless very short sections are employed. An obvious advantage is low cost.

II. CHEMICAL AGENTS

Product and Source	Manufacturer's Recommended Application Ratio(a)	Approximate Cost(b)	Remarks
Burning Agents			
Cab-O-Sil ST-2-0 Cabot Corporation	5 lb/100 gal oil (Reference 2)	\$2/lb	Produces a wicking effect to stimulate burning.
Pyraxon Guardian Chemical Corp.		\$2.90/lb	Burning reportedly starts on 1/4 in. layer.
Jelling Agents			
Spill Away Yosemite Chem. Co.	1:2	\$2.50/gal	Forms a gel with oil
Actusol T-766 DuBois Chem. Co.		\$2.50/gal	
Alken O.S.D. Alken-Murray Corp.	1:10	\$3.00/gal	Can be used on gasoline, kerosene, heating oil, jet fuel or other such hydrocarbon.
Ameroid Oil Spill Emulsifier #1 Drew Chem. Corp.	1:20	\$3.25/gal	Effective on all oils. Reference 1.
Aquaclene 100 Metropolitan Petroleum Petrochemicals Company Inc.	1:1 to 1:12		Nonsolvent, pure alkanolamides

(a) *Parts dispersant per part oil*

(b) *Based on (52-55 gal) drum quantities*

Product and Source	Manufacturer's Recommended Application Ratio[a]	Approximate Cost[b]	Remarks
Blitz **The Clarkson Laboratories, Inc.**	1:5	\$2.50/gal	Control of oil, gasoline, and jet fuel spills.
BP-1002 **British Petroleum Ltd.**		\$1.20/gal	Used extensively in TORREY CANYON cleanup. Sulfonated dodecyl benzene in kerosene.
Crain LCP-12 (Improved) **Crain Industrial Products Corp.**			Recommend mixing one part product to three parts water.
Corexit 7665 **Enjay Chemical Co.** **(See Appendix D)**	1:10	\$4.00/gal	Used extensively in Santa Barbara Channel. Non-toxic in concentrations up to 10,000 ppm (Reference 1)
Dart **Sea-Air Chem. Corp.**			
Foilzoil **Sea-Air Chem. Corp.**	10 gal/1000 ft^2 of oil slick	\$2.05/gal	
Gamosol Gamlen Co.	1:6-1:10		Meet military specification #MIL-A-22864 (Ships) "Solvent-Emulsifier, Oil Slick."
Gold Crew Bilge Cleaner **Ara Chem. Inc.**		\$2.39/gal (Ref. 3)	Should be mixed with 25 parts or more water.
Ipegal RC-520 **Igepal CO-530** **General Aniline & Film Corp.**		\$1.90/gal (1967)	Emulsifier for mineral oils, kerosene and fuel oils.
Jansolv-60 **Sunshine Chem. Corp.**	1:10	\$1.91/gal	Fuel oils. Water base. (Reference 3)

Product and Source	Manufacturer's Recommended Application Ratio[(a)]	Approximate Cost[(b)]	Remarks
Lix 336 The Lix Corporation	1:4	\$0.80/gal	Water based cleaning agent for oily surfaces.
Mighty Mate Sea-Air Chem. Corp.			
Navee-42 Amerace Corp.			
OD-2 Crain Industrial Products Corp.			One part OD-2 per square foot will disperse 6 parts oil (manufacturer).
Oil Spill Disperser Magnus Chemical	∿1:10	\$2.47/gal	Disperses gasoline, kerosene heating oil and jet fuel.
Pilot Oil Spill Eradicator		\$3.00/gal	
Polycomplex A-11 Guardian Chemical Corp.	1:10 (Ref. 1)	\$3.65/gal	Complexes the oil which reportedly enhances degradation
Sea Green 50-A Sea Light Mfg. Co. Ltd.	1:5		For crude to light-quality oils--organic solvent
Sea Green 70 Sea Light Mfg. Co. Ltd.	1:5		For heavy-quality oils, organic solvent.
Slix Amerace Corp.	1:5 or 1/2 gal per 100 ft^2 of slick		Petroleum oils, kerosene, fuel oils.
Spill Remover Wyandotte Chemical Corp.	1:5		
Spill-X Pacific Chemical		\$3.45/gal	Primarily a degreaser.

Product and Source	Manufacturer's Recommended Application Ratio[(a)]	Approximate Cost[(b)]	Remarks
Talent Wyandotte Chemical Corp.		\$2.30/gal	
Tergitol 15-S-5 Union Carbide Corp.			
Tergitol 15-5-9 Union Carbide Corp.			
Tetrolite Petrolite Corp.			Primarily for tark cleaning.
Tyfosol National Research and Chem. Co.		\$3.25/gal	Combination of amine-amido sulphonates and alkanolamide-type surface active detergents.

References for Chemical Products

1. *Oda, P., "A Report on the Laboratory Evaluation of Five Chemical Additives Used for the Removal of Oil Slicks on Water," Ontario Water Resources Commission, August 1968.*

2. *Anonymous, Chemical Engineering, February 10, 1969, page 52.*

3. *Culbertson, T. L. and Scott, A. L. "Chemical Treatment of Oil Spilled on Harbor Waters," Naval Civil Engineering Laboratory Technical Note N-938, August 1968.*

III. CHEMOMECHANICAL AGENTS

Product and Source	Constituents	Approximate Cost	Remarks
Sorbents			
Capillardiamin U. F. Chemical Corp.	Synthetic resin		Absorbs 30 to 50 times its own weight. Can be manufactured *in situs*.
Conwed Petro Sorb Type I328-3 Conwed Corp.	Wood cellulose fiber		Reportedly, absorbs 25 times its weight. 15:1 is recommended.
Ekoperl Grefco, Inc.			Will absorb up to 500% of its own weight.
Mistron Vapor Talc Cyprus Mines Corp.	Zinc stearate coated material	$3.50 for a 50 lb bag.	Non-toxic
Oilgobbler Polymer Research Corp. of America		$.50/lb in 100 pound bags	Reportedly, absorbs up to 100 times its weight in oil. Oil is recovered by heating.
Perlite	Silicone treated siliceous volcanic rock	$75/100 ft^3	Good insulating material. Water repellent, noncombustible.
Pine Tree Bark American Modoc Inc.	Powdered 0-1/8 in. aggregate	$5/33 lb bag	Two pounds of bark absorbs 1 gal of oil. Can be blown over the surface.
Polymer Foams	polyethylene, polystyrene, polypropylene and polyurethane	up to $.75/lb	Theoretically, polyurethane can absorb 100 times its own weight. Polypropylene absorbs 6 times its weight.

Product and Source	Constituents	Approximate Cost	Remarks
Sawdust			Widely available, but less effective than straw.
Straw	Wheat stalks	$25-35/ton	Reportedly, absorbs 5-30 times its own weight of oil (depending on reporting source.) Widely used but difficult to recover.
Vermiculite			Requires special treatment for effective use on oil slicks.
Sinking Agents			
Carbonized Sand			Heat treated mixture of hydrocarbons and sand.

IV. SKIMMING DEVICES

SUCTION SKIMMERS

1. Achema:

Shell Chemicals has developed a barge for oil and debris removal from harbors and waterways. A Vee-position boom facilitates the collection of oil between boom and barge. Skimming is effective at speeds up to 2 knots. Oil is sucked from the water surface through a vertical slot extending below the surface. The recovered oil is decanted and the oil-free water subsequently pumped overboard. The suction tends to draw oil from the surface area in the vicinity of the slot. The first prototype, named "Waterwisser", has an oil storage capacity of 20 tons and a water return pumping capacity of 100 tons per hour.

2. Neirad Vacuum Separator:

Neirad Industries will market a floating suction device for lifting of oil from the surface of the water. It has a triangular shape with corner floatation and comes with attached floating suction and discharge lines. The available models sell for $3750 and $7450. (See Appendix D, Figure D-11.)

3. ESSO Recovery:

The diesel-driven Esso Recovery is a converted LCM with a length of 45 ft and a beam of 14 ft. It is equipped with a Victor oily water separator and four suction skimmers. The suction skimmers are simply open-ended pipes with a dish-shaped tray arrangement held such that oily water is received and transmitted to the 30 ton per hour separator.[1]

4. Airlift Oil Recovery Device

This device uses an ejector to cause a vacuum much as in a carburator venturi. Once the suction is produced at the bell mouth nozzle, the oil is drawn into the device and through a suction hose. Once retrieved, the oily water is allowed to settle gravimetrically in a holding tank, the heavier water being removed. The ejector is of a Coanda configuration to induce greater flow efficiencies.

ROLL OR CONVEYOR SKIMMERS

1. Surface Sweeping Ship

A Japanese Corporation of Tokyo (Mitsubishi Jukogyo Kabushike) has applied for a patent on their oil skimmer design. They have a flow-through arrangement whereby an inclined conveyor belt sweeps oil or debris rearward. The debris is collected in a screen arrangement while the oil adheres to the conveyor and is scraped off with a doctor blade during the return cycle. The conveyor helps draw the oil slick and promotes forward travel. A Vee-boom arrangement is used to contain and condense the slick.

2. Oil Recovery Vessel

Oswald Hardie, Chief Engineer of the Port of Manchester, England, has designed a machine to pick up as much as 2 tons of oil per hour. Long rolls of mutton cloth or paper are passed through the water surface and recovered on rollers. The cloth or paper contacts the oil by a roller mechanism at the water line and picks up as much as 5 times its weight in oil. The oil contaminated rolls are stored and subsequently transferred to shore for disposal of both paper and sorbed oil. (See Appendix D.)

3. Sea Sweeper (England)

A vertical conveyor belt is combined with a self-propelled skimming craft to obtain an efficient integrated skimmer. Oil on the water surface adheres to the endless belt and is subsequently scraped from the belt by a blade arrangement or doctor blade. Water flows out through holes in the bottom of the recovery tank as it is displaced by incoming oil.

4. Reclaim-Ator:

A rotary skimming device is used in conjunction with a small entrance boom. The surface of the roller is covered with a foamed hydrophobic material. As the oil- and water-soaked roller comes around, a secondary roller removes water from the large drum and a small high-pressure roller then removes the oil. Average grade Bunker C can be recovered at rates up to 50 barrels per hour. Pickup capacity increases dramatically with light oils. Wells Products Corporation produces the "Reclam-Ator" skimmer; some models cost less than $11,000. The absorbent surface of the roller can be rendered inoperable by surface debris. (See Appendix D.)

5. M/V Port Service:

The oil recovery barge in the harbor of Baltimore, Maryland, (M/V Port Service) uses the rotating drum technique of oil/water separation. The steel rollers are relatively insensitive to oil viscosity, temperature, and debris and work on the principle of selective adhesive, cohesive properties of oils in water. The 38 ft, 41.2 ton displacement craft uses 4 drums each, 3 ft in diameter by 4 ft long, equipped with neoprene wiper blades. Three of the drums bring the oil into a concentrating tank whereupon the fourth roller picks up the oil (95% pure) for deposit in the barge holding tank. It can recover 200 to 500 gallons per hour and has a capacity of 3000 gallons. Waves disturb the effectiveness of the system and drum speed must also be carefully controlled for maximum effectiveness, depending on oil viscosity.

The present cost of a device similar to the Baltimore barge is approximately $105,000. The Port Authority makes the recovery barge available, upon request, for cleanup of spills in the vicinity of the harbor at a rate of $100 per hour.

WIER OR GRAVITY SKIMMERS

1. NCEL Oil Skimmer:

A small, 20 ft, plywood barge was designed and built by the Naval Civil Engineering Laboratory to incorporate design criteria such as speed, capacity, maneuverability, etc., into a craft. This craft will travel at 10-knots light; when in operation, it picks up oil by a continuously adjustable weir. The water/oil mixture is carried into a sump where the oil enters on top and displaces the recovered water through scuttle valves at the bottom. When full or when the slick has been satisfactorily picked up, the scuttle valves are closed, the craft returns to port, and the oil is pumped into a receptacle for disposal. The craft is driven by a stern-mounted outboard.

APPENDIX C

EFFECTIVENESS WORKSHEETS

C-1

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(1) SORBENTS/MANUAL RETRIEVAL + CONTAINMENT

CRITERIA

PARAMETERS

Frequency	Product	Spill Size	Water Movement
(I) ≤ 10/year (II) ≥ 50/ year	(A) Bunker C (B) Navy Special (C) JP-5 (D) Distillate Fuel	(a) ≤ 200 gallons (b) ≥ 2000 gallons	(1) Minimal (2) ≥ 1/2 Knot

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	+1	+1	+1	+1	-½	+½	+½	4½
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
(II)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								

TOTAL 144

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(2) ..ANTS/MANUAL RETRIEVAL + CONTAINMENT BOOM

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

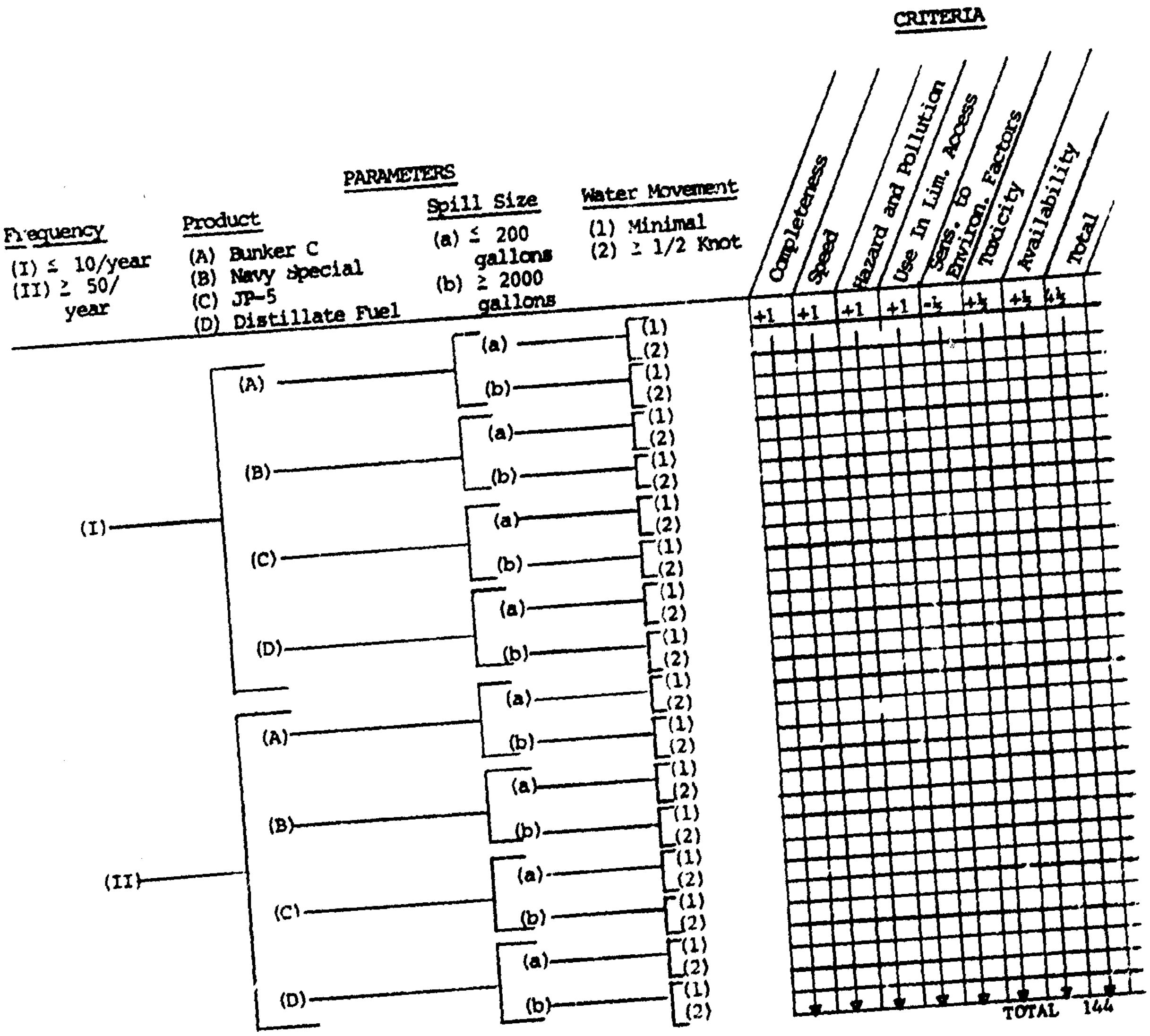
Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
				+1	+1	+1	+1	-½	+½	+½	4½
(I)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
(II)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								

TOTAL 144

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(3) SUCTION DEVICES (PORTABLE) + CONTAINMENT



EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(4) CHEMICAL DISPERSION + CONTAINMENT

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	+1	+1	+1	+1	+½	0	+½	5
			(2)			+1			+½		5½
		(b)	(1)			0			-½		4
			(2)			+1			0		5
	(B)	(a)	(1)			+1			0		5
			(2)			+1			+½		5½
		(b)	(1)			0			-½		3½
			(2)			+1			0		5
	(C)	(a)	(1)			+1			0		5
			(2)			+1			+½		5½
		(b)	(1)			+1			-½		4½
			(2)			0			-½		3½
	(D)	(a)	(1)			+1			0		5
			(2)			+1			+½		5½
		(b)	(1)			0			-½		3½
			(2)			+1			-½		4½
(II)	(A)	(a)	(1)			+1			-½		4½
			(2)			+1			0		5
		(b)	(1)			0			-½		3½
			(2)			0			-½		3½
	(B)	(a)	(1)			+1			-½		4½
			(2)			+1			0		5
		(b)	(1)			0			-½		3½
			(2)			0			-½		3½
	(C)	(a)	(1)			+1			-½		4½
			(2)			+1			0		5
		(b)	(1)			0			-½		3½
			(2)			0			-½		3½
	(D)	(a)	(1)			+1			-½		4½
			(2)			+1			0		5
		(b)	(1)			0			-½		3½
			(2)			0			-½		3½
									TOTAL		141½

C-5

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(5) SORBENTS/CONVEYOR (SELF-PROPELLED) + CONTAINMENT BOOM

CRITERIA

PARAMETERS

Frequency	Product	Spill Size	Water Movement
(I) ≤ 10/year	(A) Bunker C	(a) ≤ 200 gallons	(1) Minimal
(II) ≥ 50/ year	(B) Navy Special	(b) ≥ 2000 gallons	(2) ≥ 1/2 Knot
	(C) JP-5		
	(D) Distillate Fuel		

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	0	½	½	0	4
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
(II)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								

TOTAL 128

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(6) GELLANTS/CONVEYOR (SELF-PROPELLED) + CONTAINMENT BOOM

CRITERIA

Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
1	1	1	0	½	½	0	4

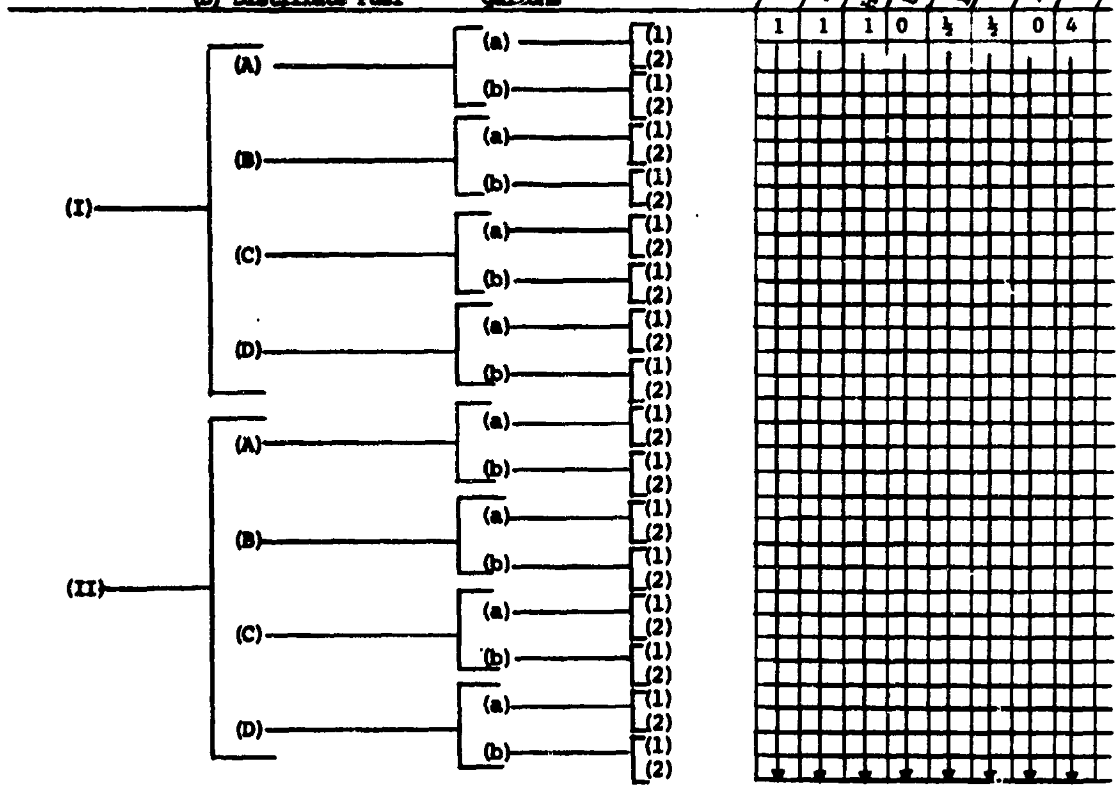
PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot



TOTAL 128

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(7) ENDLESS BELT ON WATER SURFACE + CONTAINMENT BOOM

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	0	½	½	0	4
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
(II)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								

TOTAL 128

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(8) CHEMICAL DISPERSANTS APPLIED DIRECTLY TO SLICK (INCLUDES AUXILIARY AGITATION)

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	0	1	½	0	½	4
			(2)			1			½		5½
		(b)	(1)			0			-½		3½
			(2)						0		4
	(B)	(a)	(1)								
			(2)			1			½		5½
		(b)	(1)			0			-½		3½
			(2)						0		4
	(C)	(a)	(1)								
			(2)			1			½		5½
		(b)	(1)			0			-½		3½
			(2)						0		4
	(D)	(a)	(1)								
			(2)			1			½		5½
		(b)	(1)			0			-½		3½
			(2)						0		4
(II)	(A)	(a)	(1)						-½		3½
			(2)			1			0		5
		(b)	(1)			-1			-½		2½
			(2)			0					3½
	(B)	(a)	(1)								
			(2)			1			0		5
		(b)	(1)			-1			-½		2½
			(2)			0					3½
	(C)	(a)	(1)								
			(2)			1			0		5
		(b)	(1)			-1			-½		2½
			(2)			0					3½
	(D)	(a)	(1)								
			(2)			1			0		5
		(b)	(1)			-1			-½		2½
			(2)			0			-½		3½

TOTAL 126

C-9

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(9) SORBENTS/SUCTION DEVICE + CONTAINMENT

CRITERIA

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/ year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	0	0	0	1	-½	½	½	1½
(I)	(A)	(a)	(2)								
(I)	(A)	(b)	(1)								
(I)	(A)	(b)	(2)	1	1	1					4½
(I)	(B)	(a)	(1)								
(I)	(B)	(a)	(2)								
(I)	(B)	(b)	(1)								
(I)	(B)	(b)	(2)								
(I)	(C)	(a)	(1)								
(I)	(C)	(a)	(2)								
(I)	(C)	(b)	(1)								
(I)	(C)	(b)	(2)								
(I)	(D)	(a)	(1)								
(I)	(D)	(a)	(2)								
(I)	(D)	(b)	(1)								
(I)	(D)	(b)	(2)								
(II)	(A)	(a)	(1)	0	0	0					1½
(II)	(A)	(a)	(2)								
(II)	(A)	(b)	(1)								
(II)	(A)	(b)	(2)								
(II)	(B)	(a)	(1)	1	1	1					4½
(II)	(B)	(a)	(2)								
(II)	(B)	(b)	(1)								
(II)	(B)	(b)	(2)								
(II)	(C)	(a)	(1)								
(II)	(C)	(a)	(2)								
(II)	(C)	(b)	(1)								
(II)	(C)	(b)	(2)								
(II)	(D)	(a)	(1)								
(II)	(D)	(a)	(2)								
(II)	(D)	(b)	(1)								
(II)	(D)	(b)	(2)								

TOTAL 120

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(10) ROTATING DRUMS (NON SORBENT SURFACE) + CONTAINMENT BOOM (SELF-PROPELLED)

CRITERIA

PARAMETERS

Frequency	Product	Spill Size	Water Movement
(I) ≤ 10/year	(A) Bunker C	(a) ≤ 200 gallons	(1) Minimal
(II) ≥ 50/year	(B) Navy Special	(b) ≥ 2000 gallons	(2) ≥ 1/2 Knot
	(C) JP-5		
	(D) Distillate Fuel		

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	0	0	½	0	3½
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
(II)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								

TOTAL 112

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(11) GRAVITY SKIMMER + FLOATING BOOM (SELF-PROPELLED)

PARAMETERS

Frequency	Product	Spill Size	Water Movement
(I) ≤ 10/year	(A) Bunker C	(a) ≤ 200 gallons	(1) Minimal
(II) ≥ 50/ year	(B) Navy Special	(b) ≥ 2000 gallons	(2) ≥ 1/2 Knot
	(C) JP-5		
	(D) Distillate Fuel		

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Line, Access	Safe. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	0	0	½	0	3½
(I)	(A)	(a)	(2)								
(I)	(A)	(b)	(1)								
(I)	(A)	(b)	(2)								
(I)	(B)	(a)	(1)								
(I)	(B)	(a)	(2)								
(I)	(B)	(b)	(1)								
(I)	(B)	(b)	(2)								
(I)	(C)	(a)	(1)								
(I)	(C)	(a)	(2)								
(I)	(C)	(b)	(1)								
(I)	(C)	(b)	(2)								
(I)	(D)	(a)	(1)								
(I)	(D)	(a)	(2)								
(I)	(D)	(b)	(1)								
(I)	(D)	(b)	(2)								
(II)	(A)	(a)	(1)								
(II)	(A)	(a)	(2)								
(II)	(A)	(b)	(1)								
(II)	(A)	(b)	(2)								
(II)	(B)	(a)	(1)								
(II)	(B)	(a)	(2)								
(II)	(B)	(b)	(1)								
(II)	(B)	(b)	(2)								
(II)	(C)	(a)	(1)								
(II)	(C)	(a)	(2)								
(II)	(C)	(b)	(1)								
(II)	(C)	(b)	(2)								
(II)	(D)	(a)	(1)								
(II)	(D)	(a)	(2)								
(II)	(D)	(b)	(1)								
(II)	(D)	(b)	(2)								

TOTAL 112

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(12) ROTATING DRUM (SORBENT SURFACE) + CONTAINMENT BOOM (SELF-PROPELLED)

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	0	0	½	0	3½
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
(II)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								

TOTAL 112

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(13) SORBENTS/SUCTION DEVICE (ASSUMES THAT SUCTION DEVICE WILL NOT BE PLUGGED BY SORBENT) SUCTION DEVICE ADAPTABLE TO ANY VESSEL

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
				-1	-1	1	1	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
(I)	(A)	(a)	(1)								
			(2)								
		(b)	(1)			0					$-\frac{1}{2}$
			(2)								
	(B)	(a)	(1)	0	0	1					$2\frac{1}{2}$
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)	1	1	1					$4\frac{1}{2}$
			(2)								
		(b)	(1)								
			(2)	0	0	1					$2\frac{1}{2}$
	(D)	(a)	(1)	1	1	1					$4\frac{1}{2}$
			(2)								
		(b)	(1)								
			(2)	0	0	1					$2\frac{1}{2}$
(II)	(A)	(a)	(1)	-1	-1	0					$-\frac{1}{2}$
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)	0	0	1					$2\frac{1}{2}$
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)	1	1	1					$4\frac{1}{2}$
			(2)								
		(b)	(1)								
			(2)	0	0						$2\frac{1}{2}$
	(D)	(a)	(1)	1	1						$4\frac{1}{2}$
			(2)								
		(b)	(1)								
			(2)	0	0						$2\frac{1}{2}$
										TOTAL	82

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(14) MECHANICAL RETRIEVAL WITH GRAVITY SKIMMER (SELF-PROPELLED)

PARAMETERS

Frequency	Product	Spill Size	Water Movement
(I) ≤ 10/year	(A) Bunker C	(a) ≤ 200 gallons	(1) Minimal
(II) ≥ 50/ year	(B) Navy Special	(b) ≥ 2000 gallons	(2) ≥ 1/2 Knot
	(C) JP-5		
	(D) Distillate Fuel		

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	-1	0	½	0	2½
			(2)								
		(b)	(1)								
			(2)			0					1½
	(B)	(a)	(1)			1	0				3½
			(2)								
		(b)	(1)								
			(2)	0		0					1½
	(C)	(a)	(1)	1		1					3½
			(2)		0						2½
		(b)	(1)	0	1						2½
			(2)	0	0						1½
	(D)	(a)	(1)	1	1						3½
			(2)	1	0						2½
		(b)	(1)	0	1						2½
			(2)	0	0						1½
(II)	(A)	(a)	(1)	1	1		-1				2½
			(2)								
		(b)	(1)								
			(2)	0		0					½
	(B)	(a)	(1)	1		1	0				3½
			(2)								
		(b)	(1)								
			(2)	0		0					1½
	(C)	(a)	(1)	1		1					3½
			(2)	1	0						2½
		(b)	(1)	0	1						2½
			(2)	0	0						1½
	(D)	(a)	(1)	1	1						3½
			(2)	1	0						2½
		(b)	(1)	0	1						2½
			(2)	0	0						1½

TOTAL 81

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(15) CHEMICAL BURNING AGENTS + CONTAINMENT

CRITERIA

Completeness | Speed | Hazard and Pollution | Use In Lim. Access | Sens. to Environ. Factors | Toxicity | Availability | Total

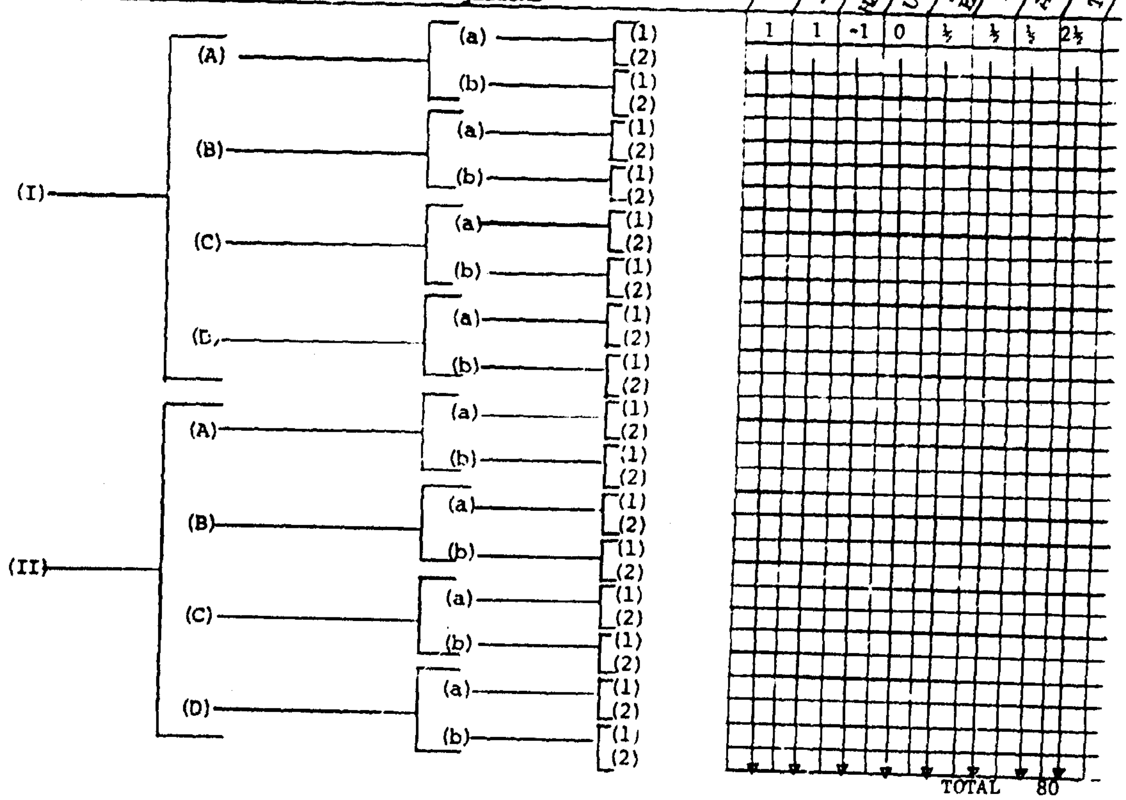
PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/ year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot



EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(16) SINKING AGENTS APPLIED DIRECTLY TO SLICK

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use in Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	0	1	½	0	½	4
			(2)								
		(b)	(1)			-1			-1		2
			(2)								
	(B)	(a)	(1)			0			0		4
			(2)								
		(b)	(1)			-1			-1		2
			(2)								
	(C)	(a)	(1)			0					3
			(2)								
		(b)	(1)			-1					2
			(2)								
	(D)	(a)	(1)			0					3
			(2)								
		(b)	(1)			-1					2
			(2)								
(II)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								

TOTAL 76

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(17) SINKING AGENTS + CONTAINMENT BOOM

PARAMETERS

Frequency	Product	Spill Size	Water Movement
(I) ≤ 10/year	(A) Bunker C	(a) ≤ 200 gallons	(1) Minimal
(II) ≥ 50/ year	(B) Navy Special	(b) ≥ 2000 gallons	(2) ≥ 1/2 Knot
	(C) JP-5		
	(D) Distillate Fuel		

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	0	1	½	0	½	4
			(2)								
		(b)	(1)			-1			-1		2
			(2)								
	(B)	(a)	(1)			0			0		4
			(2)								
		(b)	(1)			-1			-1		2
			(2)								
	(C)	(a)	(1)			0					3
			(2)								
		(b)	(1)			-1					2
			(2)								
	(D)	(a)	(1)			0					3
			(2)								
		(b)	(1)			-1					2
			(2)								
(II)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								

TOTAL 76

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(18) SORBENTS/CONVEYOR (SELF PROPELLED)

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	-1	½	½	0	3
			(2)	↓	↓						↓
		(b)	(1)	↓	0						2
			(2)	0	↓						1
	(B)	(a)	(1)	1	1						3
			(2)								
		(b)	(1)	↓							↓
			(2)	0							2
	(C)	(a)	(1)	1							3
			(2)		↓						↓
		(b)	(1)	↓	0						2
			(2)	0	-1						0
	(D)	(a)	(1)	1	1						3
			(2)								
		(b)	(1)	↓							↓
			(2)	0							2
(II)	(A)	(a)	(1)	1							3
			(2)								
		(b)	(1)	↓	↓						↓
			(2)	0	0						1
	(B)	(a)	(1)	[illegible]	↓						2
			(2)								3
		(b)	(1)	↓	↓						↓
			(2)	0	0						1
	(C)	(a)	(1)	1	1						3
			(2)		↓						↓
		(b)	(1)	↓	0						2
			(2)	0	-1						0
	(D)	(a)	(1)	1	1						3
			(2)		↓						↓
		(b)	(1)	↓	0						2
			(2)	0	↓	↓	↓	↓	↓	↓	1

TOTAL 75

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(19) GELLANTS/CONVEYOR (SELF-PROPELLED)

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/ year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	-1	½	½	0	3
			(2)	↓	↓						↓
		(b)	(1)	↓	0						2
			(2)	0	↓						1
	(B)	(a)	(1)	1	1						3
			(2)	↓	↓						↓
		(b)	(1)	↓	↓						↓
			(2)	0	0						1
	(C)	(a)	(1)	1	1						3
			(2)	↓	↓						↓
		(b)	(1)	↓	0						2
			(2)	0	↓						1
	(D)	(a)	(1)	1	1						3
			(2)	↓	↓						↓
		(b)	(1)	↓	0						2
			(2)	0	↓						1
(II)	(A)	(a)	(1)	1	1						3
			(2)	↓	↓						↓
		(b)	(1)	↓	0						2
			(2)	0	↓						1
	(B)	(a)	(1)	1	1						3
			(2)	↓	↓						↓
		(b)	(1)	↓	↓						↓
			(2)	0	0						1
	(C)	(a)	(1)	1	1						3
			(2)	↓	↓						↓
		(b)	(1)	↓	0						2
			(2)	0	↓						1
	(D)	(a)	(1)	1	1						3
			(2)	↓	↓						↓
		(b)	(1)	↓	0						2
			(2)	0	↓	↓	↓	↓	↓	↓	1

TOTAL 74

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(20) SUCTION DEVICES (PORTABLE)

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	0	0	1	1	-½	½	½	2½
			(2)								
		(b)	(1)	↓	↓	↓					↓
			(2)	-1	-1	0					-½
	(B)	(a)	(1)	1	1	1					4½
			(2)	↓	↓						↓
		(b)	(1)	0	0	↓					2½
			(2)	-1	-1	0					-½
	(C)	(a)	(1)	1	1	1					4½
			(2)	0	0						2½
		(b)	(1)	↓	↓	↓					↓
			(2)	-1	-1	0					-½
	(D)	(a)	(1)	1	1	1					4½
			(2)	0	0						2½
		(b)	(1)	↓	↓						↓
			(2)	-1	-1	↓					-½
(II)	(A)	(a)	(1)	0	0	1					2½
			(2)								
		(b)	(1)	↓	↓	↓					↓
			(2)	-1	-1	0					-½
	(B)	(a)	(1)	1	1	1					4½
			(2)	↓	↓	↓					↓
		(b)	(1)	0	0	1					2½
			(2)	-1	-1	0					-½
	(C)	(a)	(1)	1	1	1					4½
			(2)	0	0	1					2½
		(b)	(1)	↓	↓	↓					↓
			(2)	-1	-1	0					-½
	(D)	(a)	(1)	1	1	1					4½
			(2)	↓	↓	↓					↓
		(b)	(1)	0	0	1					2½
			(2)	-1	-1	0	↓	↓	↓	↓	-½

TOTAL 74

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(21) ENDLESS BELT ON WATER SURFACE (SELF-PROPELLED)

CRITERIA

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	0	1/2	1/2	0	4
			(2)	↓	↓	↓	↓	↓	↓	↓	↓
		(b)	(1)	↓	↓	↓	↓	↓	↓	↓	↓
			(2)	0	0	0	↓	↓	↓	↓	1
	(B)	(a)	(1)	1	1	1	↓	↓	↓	↓	4
			(2)	↓	↓	↓	↓	↓	↓	↓	↓
		(b)	(1)	↓	↓	↓	↓	↓	↓	↓	↓
			(2)	0	0	0	↓	↓	↓	↓	1
	(C)	(a)	(1)	1	1	1	↓	↓	↓	↓	4
			(2)	1	0	0	↓	↓	↓	↓	2
		(b)	(1)	0	0	1	↓	↓	↓	↓	2
			(2)	-1	-1	0	↓	↓	↓	↓	-1
	(D)	(a)	(1)	1	1	1	↓	↓	↓	↓	4
			(2)	1	0	0	↓	↓	↓	↓	2
		(b)	(1)	0	0	1	↓	↓	↓	↓	2
			(2)	-1	-1	0	↓	↓	↓	↓	-1
(II)	(A)	(a)	(1)	1	1	1	↓	↓	↓	↓	4
			(2)	↓	↓	↓	↓	↓	↓	↓	↓
		(b)	(1)	↓	0	↓	↓	↓	↓	↓	3
			(2)	-1	-1	0	↓	↓	↓	↓	-1
	(B)	(a)	(1)	1	1	1	↓	↓	↓	↓	4
			(2)	↓	↓	↓	↓	↓	↓	↓	↓
		(b)	(1)	0	0	1	↓	↓	↓	↓	2
			(2)	-1	-1	0	↓	↓	↓	↓	-1
	(C)	(a)	(1)	1	1	1	↓	↓	↓	↓	4
			(2)	0	0	0	↓	↓	↓	↓	1
		(b)	(1)	↓	↓	1	↓	↓	↓	↓	2
			(2)	-1	-1	0	↓	↓	↓	↓	-1
	(D)	(a)	(1)	1	1	1	↓	↓	↓	↓	4
			(2)	0	0	0	↓	↓	↓	↓	1
		(b)	(1)	↓	↓	1	↓	↓	↓	↓	2
			(2)	-1	-1	0	↓	↓	↓	↓	-1
									TOTAL		71

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(22) ROTATING DRUMS (NON SORBENT SURFACE) - (SELF-PROPELLED)

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/ year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	-1	0	½	0	2½
			(2)								
		(b)	(1)	↓	↓	↓					↓
			(2)	0	0	0					-½
	(B)	(a)	(1)	1	1	1					2½
			(2)								
		(b)	(1)	↓	↓	↓					↓
			(2)	0	0	0					-½
	(C)	(a)	(1)	1	1	1					2½
			(2)	↓							↓
		(b)	(1)	0	↓	↓					1½
			(2)	-1	0	0					-1½
	(D)	(a)	(1)	1	1	1					2½
			(2)		↓						↓
		(b)	(1)	↓	0	↓					1½
			(2)	0	0	0					-½
(II)	(A)	(a)	(1)	1	1	1					2½
			(2)		↓						↓
		(b)	(1)	↓	0	↓					1½
			(2)	0	0	0					-½
	(B)	(a)	(1)	1	1	1					2½
			(2)								
		(b)	(1)	↓	↓	↓					↓
			(2)	0	0	0					-½
	(C)	(a)	(1)	1	1	1					2½
			(2)								↓
		(b)	(1)	0	↓	↓					1½
			(2)	-1	0	0					-1½
	(D)	(a)	(1)	1	1	1					2½
			(2)								
		(b)	(1)	↓	↓	↓					↓
			(2)	0	1	0	↓	↓	↓	↓	½
									TOTAL		51

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(23) GELLANTS/MANUAL RETRIEVAL

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	-1	1	1	-½	½	½	2½
			(2)	↓		↓					↓
		(b)	(1)	↓		↓					↓
			(2)	0		0					½
	(B)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	↓		↓					↓
			(2)	0		0					½
	(C)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		0					½
			(2)	-1		0					-½
	(D)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		0					½
			(2)	-1		0					-½
(II)	(A)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		↓					1½
			(2)	↓		0					½
	(B)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		↓					1½
			(2)	↓		0					½
	(C)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		0					½
			(2)	-1		0					-½
	(D)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		0					½
			(2)	-1	↓	0	↓	↓	↓	↓	-½

TOTAL 50

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(24) SORBENTS/MANUAL RETRIEVAL

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/ year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	-1	1	1	-½	½	½	2½
			(2)	↓	↓	↓	↓	↓	↓	↓	↓
		(b)	(1)	↓		↓					↓
			(2)	0		0					½
	(B)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	↓		0					1½
			(2)	0		0					½
	(C)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		0					½
			(2)	-1		0					-½
	(D)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		0					½
			(2)	-1		0					-½
(II)	(A)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		0					½
			(2)	↓		↓					↓
	(B)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		0					½
			(2)	↓		↓					↓
	(C)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		0					½
			(2)	-1		0					-½
	(D)	(a)	(1)	1		1					2½
			(2)	↓		↓					↓
		(b)	(1)	0		0					½
			(2)	-1	↓	0	↓	↓	↓	↓	-½

TOTAL 47

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(25) DOTATING DRUM WITH SORBENT SURFACE (SELF/PROPELLED)

CRITERIA

PARAMETERS

Frequency	Product	Spill Size	Water Movement
(I) ≤ 10/year	(A) Bunker C	(a) ≤ 200 gallons	(1) Minimal
(II) ≥ 50/year	(B) Navy Special	(b) ≥ 2000 gallons	(2) ≥ 1/2 Knot
	(C) JP-5		
	(D) Distillate Fuel		

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	1	1	1	-1	0	½	0	2½
			(2)	↓	↓	↓					↓
		(b)	(1)	0	↓	↓					1½
			(2)	0	0	0					-½
	(B)	(a)	(1)	1	1	1					2½
			(2)	↓	↓	↓					↓
		(b)	(1)	0	↓	↓					1½
			(2)	-1	0	0					-1½
	(C)	(a)	(1)	1	1	1					2½
			(2)	↓	0	0					½
		(b)	(1)	0	0	1					½
			(2)	-1	-1	0					-2½
	(D)	(a)	(1)	1	1	1					2½
			(2)	1	0	1					1½
		(b)	(1)	0	1	1					1½
			(2)	-1	0	0					-1½
(II)	(A)	(a)	(1)	1	1	1					2½
			(2)								
		(b)	(1)	↓	↓	↓					↓
			(2)	0	0	0					-½
	(B)	(a)	(1)	1	1	1					2½
			(2)	↓							↓
		(b)	(1)	0	↓	↓					1½
			(2)	0	0	0					-½
	(C)	(a)	(1)	1	1	1					2½
			(2)	↓	↓	↓					↓
		(b)	(1)	0	0	1					½
			(2)	-1	0	0					-1½
	(D)	(a)	(1)	1	1	1					2½
			(2)	↓							↓
		(b)	(1)	0	↓	↓					1½
			(2)	-1	0	0	↓	↓	↓	↓	-1½

TOTAL 38

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(26) CHEMICAL BURNING AGENTS

PARAMETERS

Frequency
(I) ≤ 10/year
(II) ≥ 50/year

Product
(A) Bunker C
(B) Navy Special
(C) JP-5
(D) Distillate Fuel

Spill Size
(a) ≤ 200 gallons
(b) ≥ 2000 gallons

Water Movement
(1) Minimal
(2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
				0	1	-1	-1	0	½	½	0
(I)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
(II)	(A)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(B)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(C)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								
	(D)	(a)	(1)								
			(2)								
		(b)	(1)								
			(2)								

TOTAL 0

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM:

(27) ENHANCED DEGRADATION (ADDITION OF BACTERIA, ETC.) - DOES NOT INCLUDE CHEMICAL DISPERSANTS

PARAMETERS

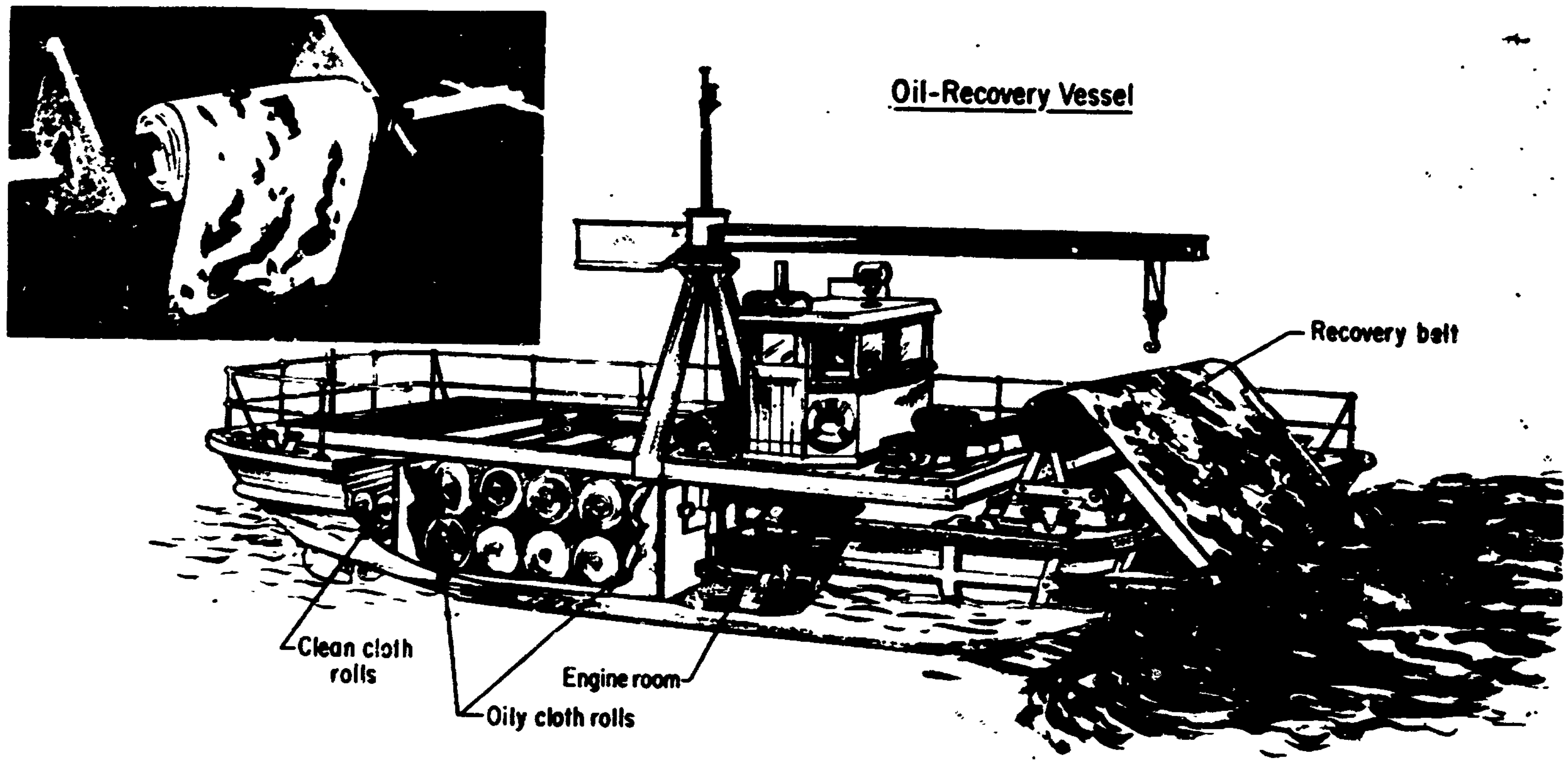
Frequency	Product	Spill Size	Water Movement
(I) ≤ 10/year (II) ≥ 50/ year	(A) Bunker C (B) Navy Special (C) JP-5 (D) Distillate Fuel	(a) ≤ 200 gallons (b) ≥ 2000 gallons	(1) Minimal (2) ≥ 1/2 Knot

CRITERIA

Frequency	Product	Spill Size	Water Movement	Completeness	Speed	Hazard and Pollution	Use In Lim. Access	Sens. to Environ. Factors	Toxicity	Availability	Total
(I)	(A)	(a)	(1)	-1	-1	0	1	0	½	½	0
			(2)			-1					-1
		(b)	(1)								
			(2)			↓					↓
	(B)	(a)	(1)			0					0
			(2)			-1					-1
		(b)	(1)								
			(2)			↓					↓
	(C)	(a)	(1)			0					0
			(2)			-1					-1
		(b)	(1)								
			(2)			↓					↓
	(D)	(a)	(1)			0					0
			(2)			-1					-1
		(b)	(1)								
			(2)			↓					↓
(II)	(A)	(a)	(1)			0					0
			(2)			-1					-1
		(b)	(1)								
			(2)			↓					↓
	(B)	(a)	(1)			0					0
			(2)			-1					-1
		(b)	(1)								
			(2)			↓					↓
	(C)	(a)	(1)			0					0
			(2)			-1					-1
		(b)	(1)								
			(2)			↓					↓
	(D)	(a)	(1)			0					0
			(2)			-1					-1
		(b)	(1)								
			(2)	↓	↓	↓	↓	↓	↓	↓	↓
										TOTAL	-24

APPENDIX D

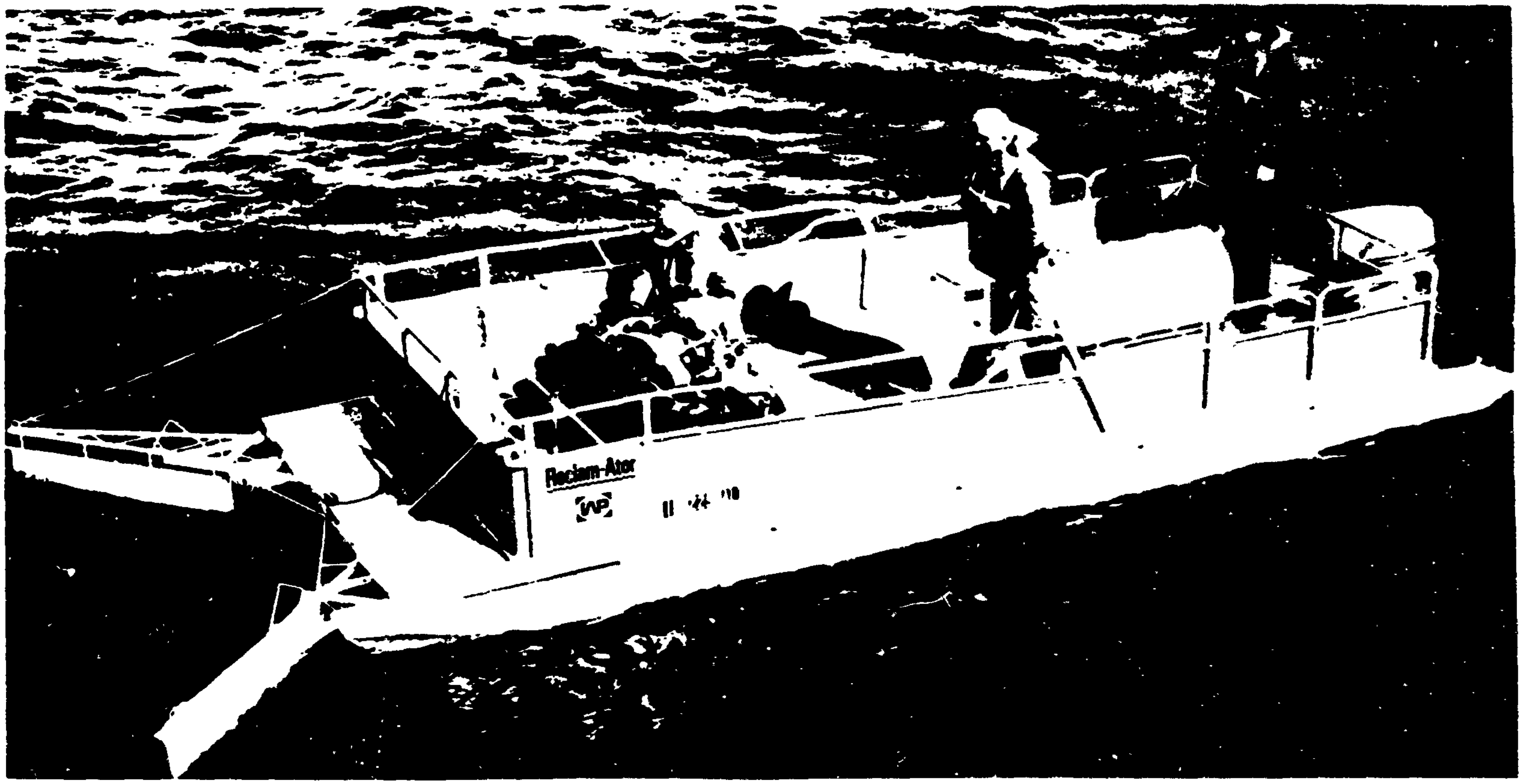
PHOTOGRAPHS AND DRAWINGS OF TYPICAL SYSTEMS AND EQUIPMENT



Proposed British vessel would pick up oil film on large cloth rollers (inset).

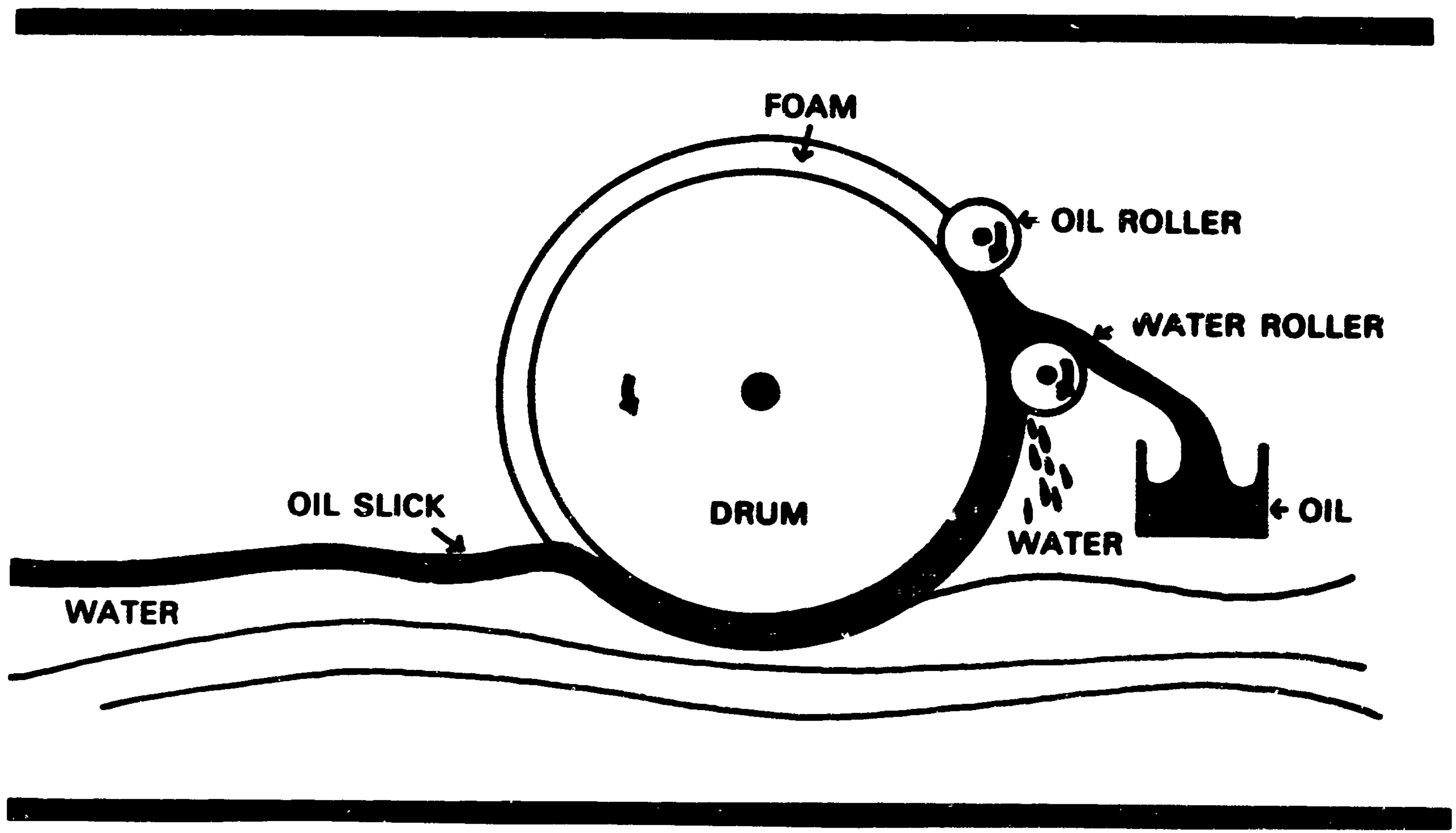
Neg 0693349-5

FIGURE D-1. *Mutton Cloth Roll Skimmer Developed by Oswald Hardie, Chief Engineer, Port of Manchester, England.*



Neg 0693349-6

FIGURE D-2. "Reclam-Ator" Skimmer (Courtesy Wells Products)



Neg 0693349-1

<u>FIGURE D-3</u>. "Reclam-Ator" Roll Skimming Mechanism (courtesy Wells Products)

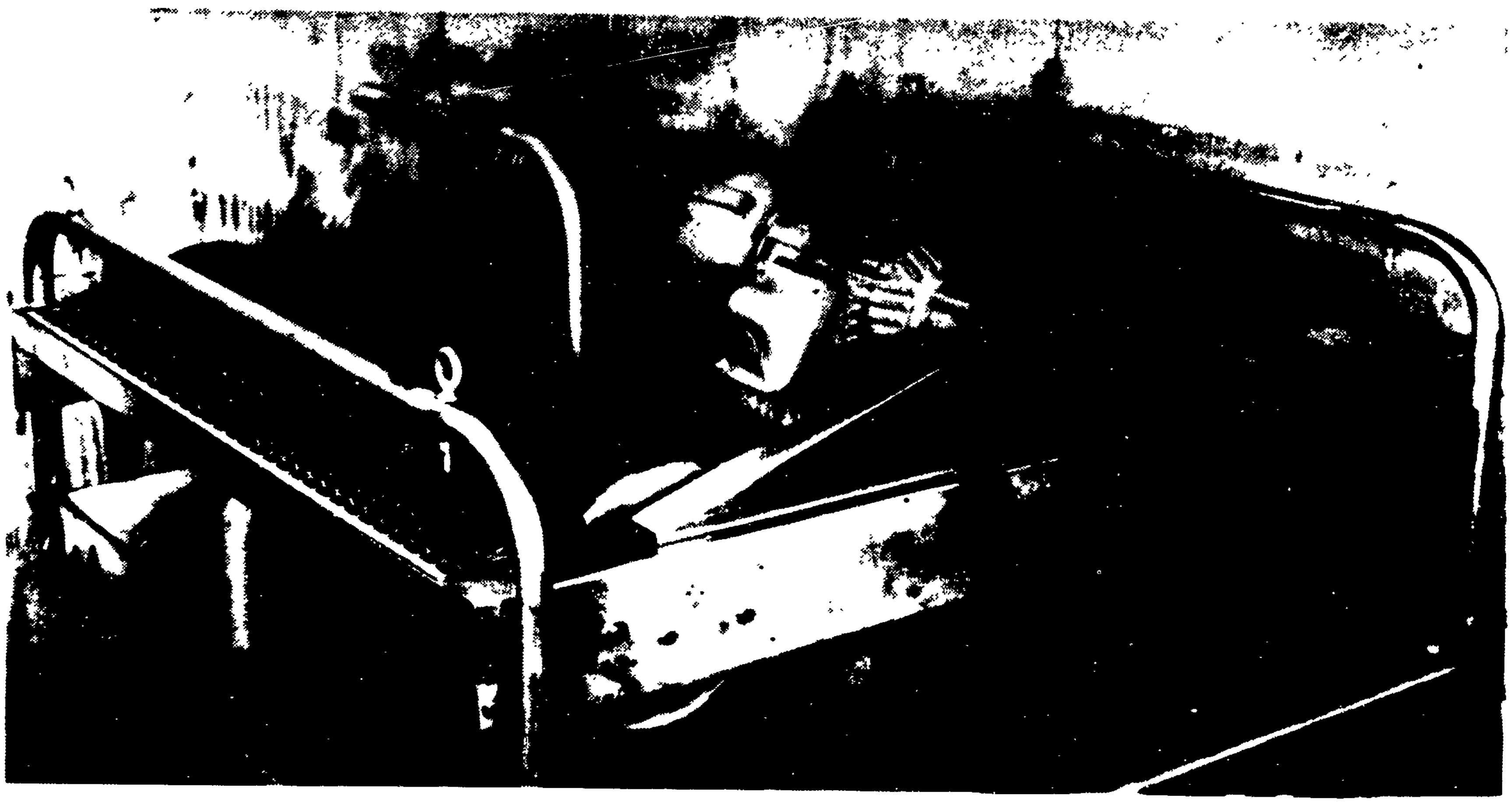
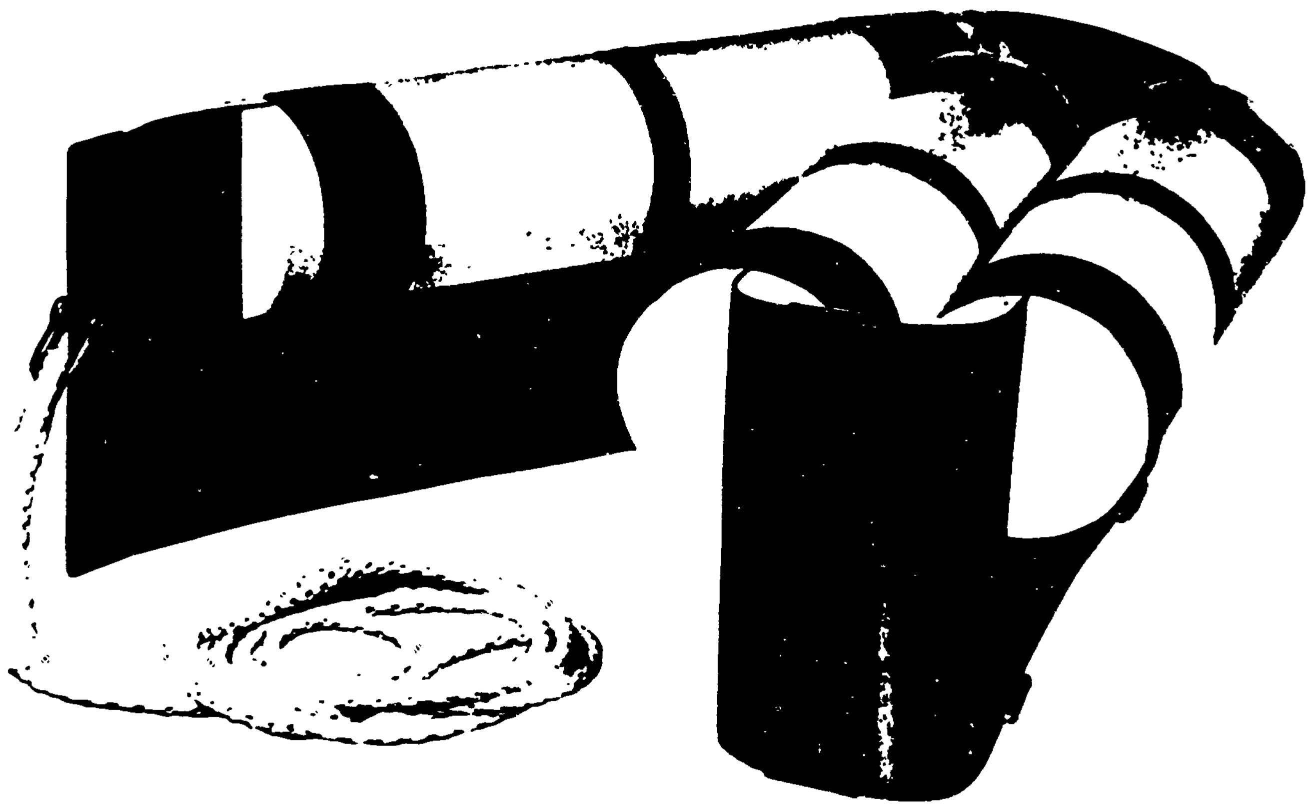


FIGURE D-4. *Fixed Oil Skimmer, Model BD-213 (courtesy Surface Separator Systems, Inc.) Photo credit to Hughes Co., Baltimore.*



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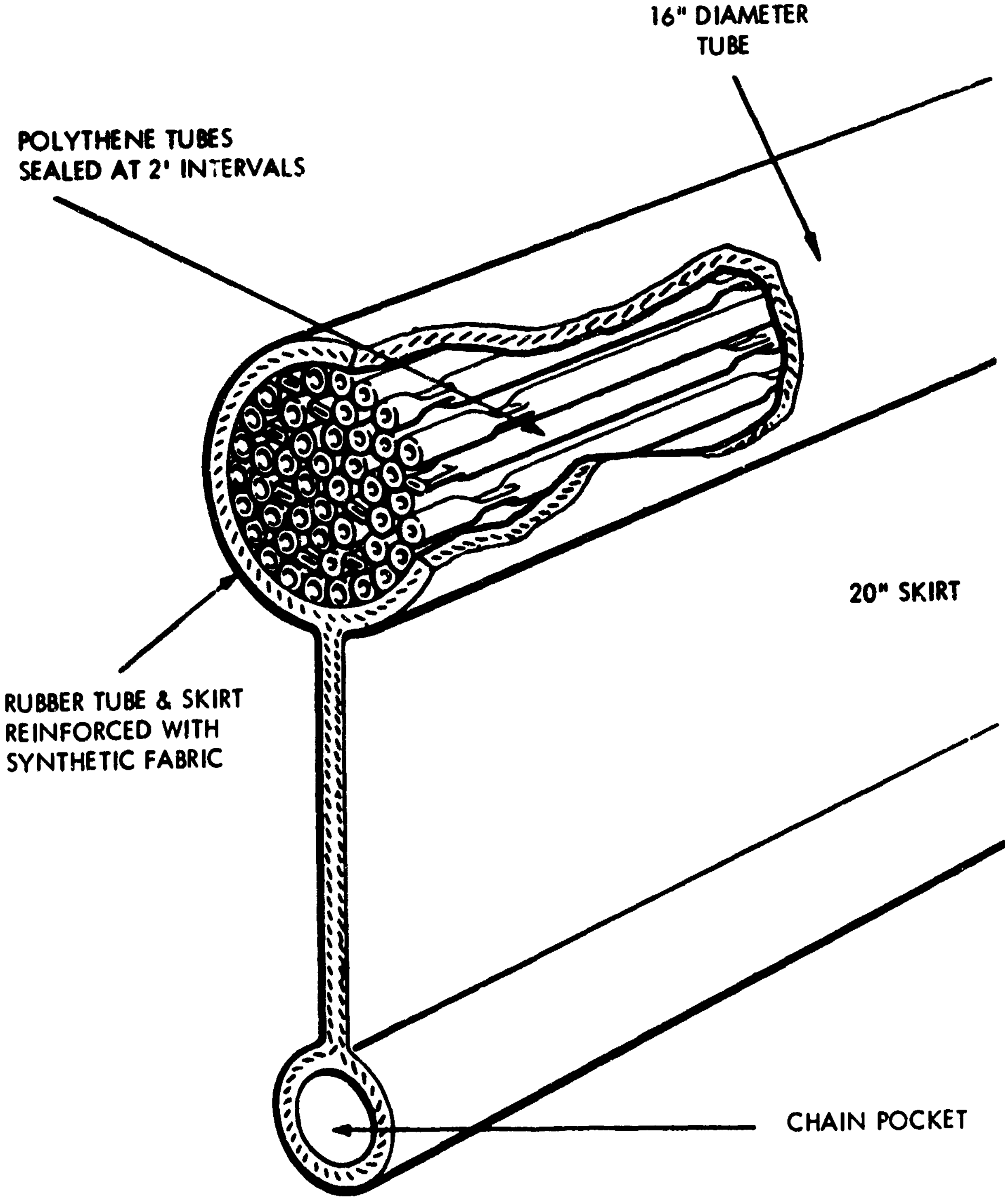
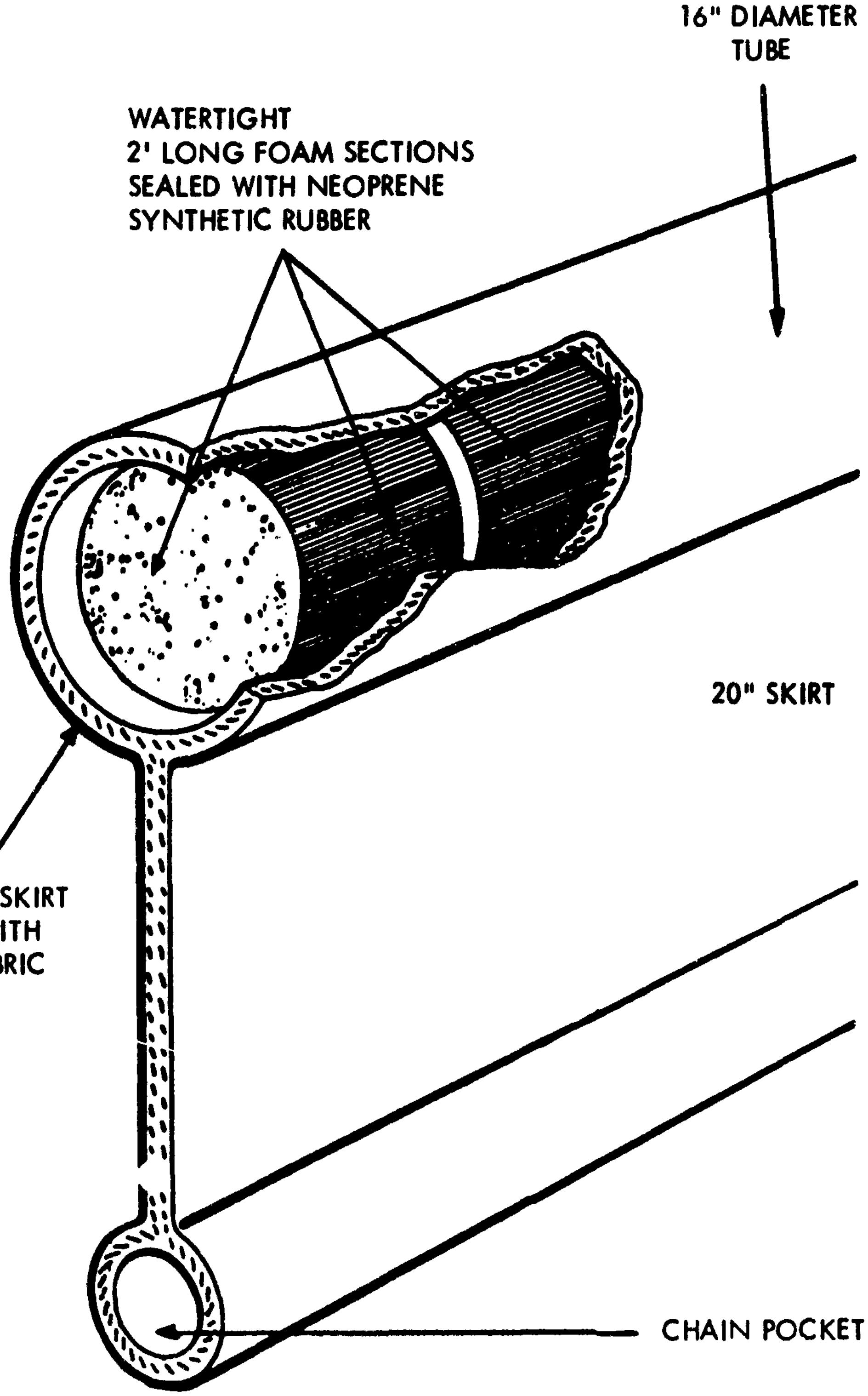
<u>FIGURE D-5</u>. *Slickbar Oil Spill Boom (courtesy Neirad Industries, Inc.)*



Neg 0693349-8

FIGURE D-6. Warne Tube-Filled Boom (courtesy William Warne and Company, Ltd.)



Neg 0693349-7

FIGURE D-7. Warne Foam-Filled Boom (courtesy William Warne and Company, Ltd.)

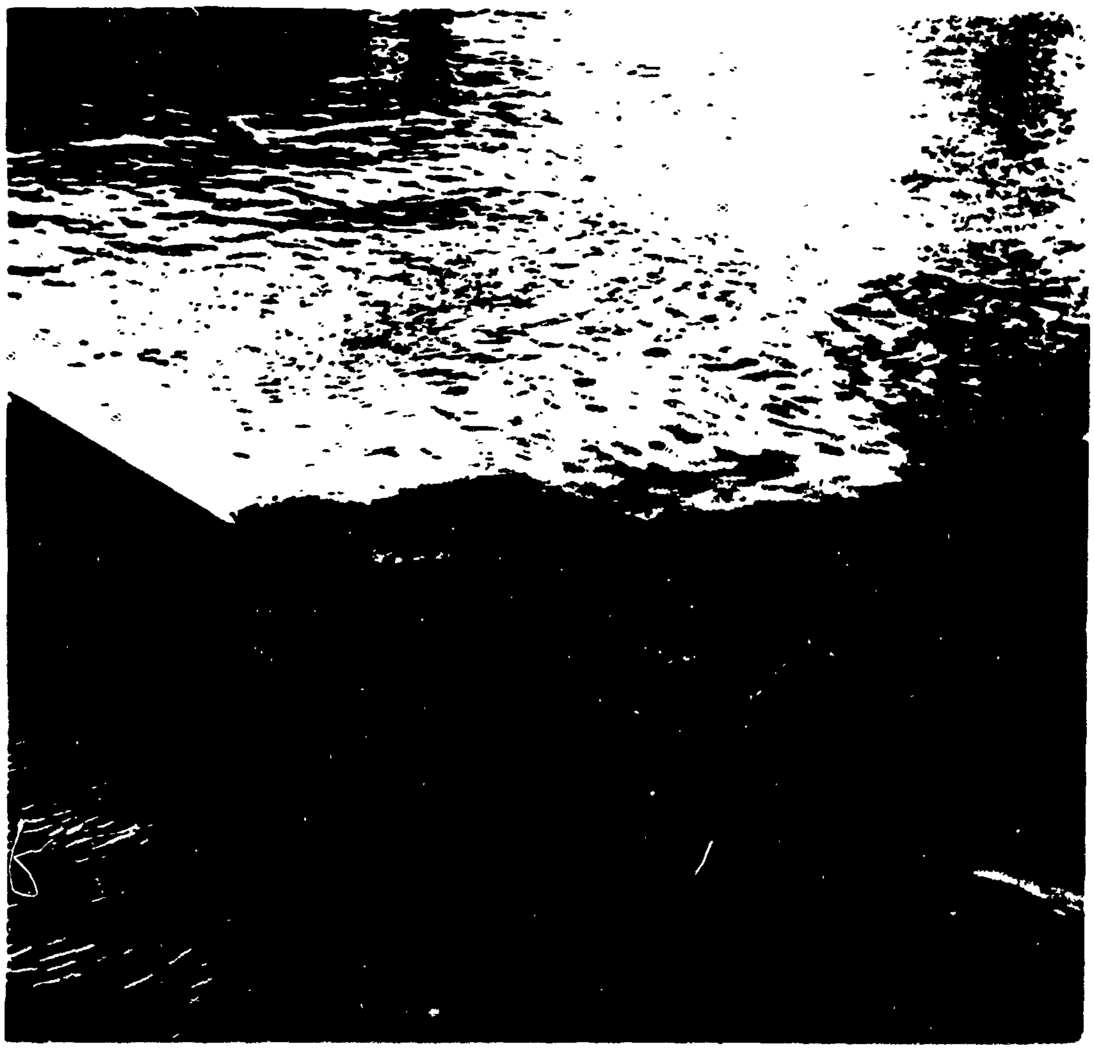
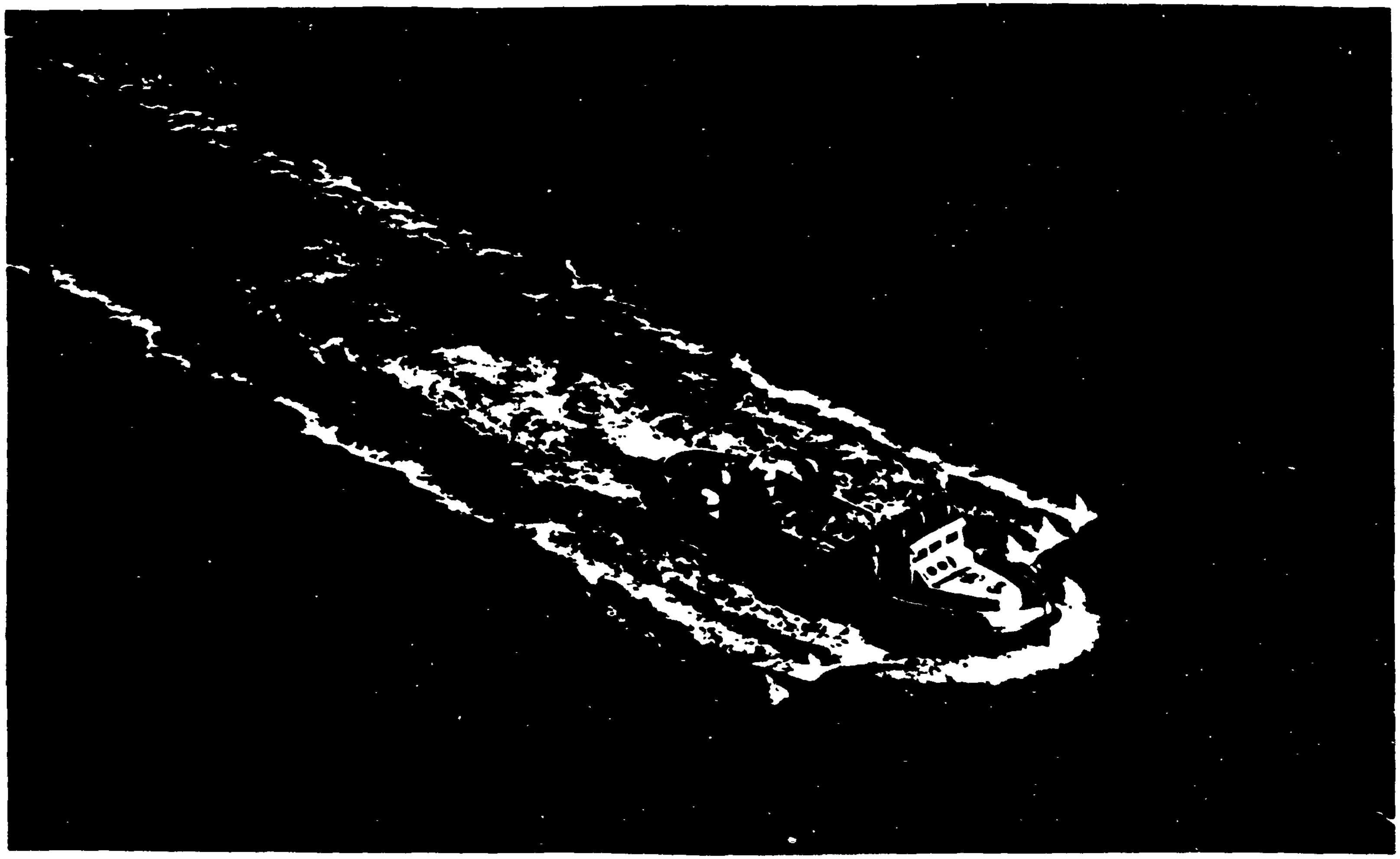
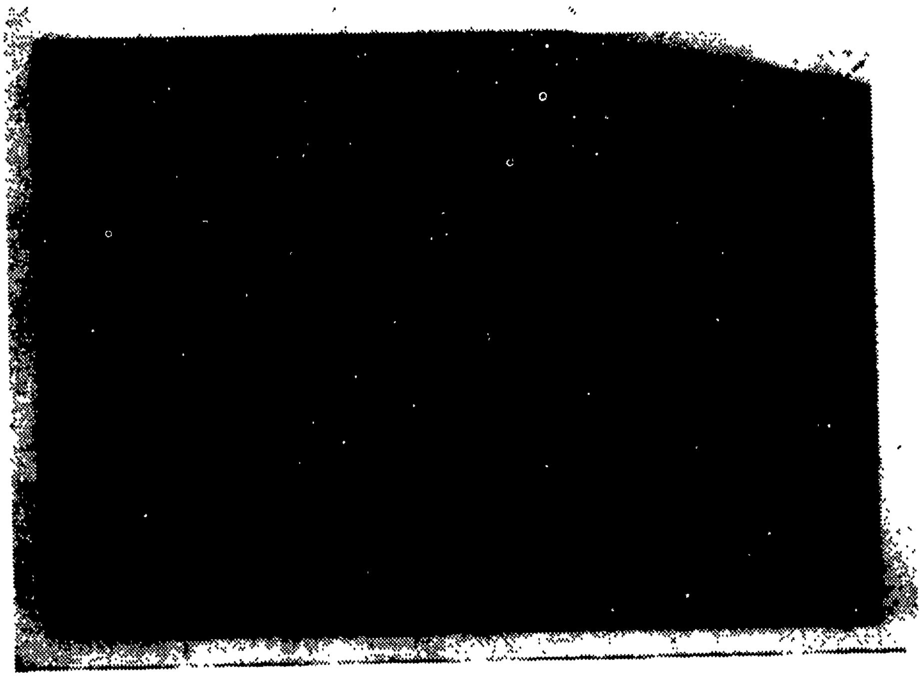


FIGURE D-8. *Warne Inflatable Boom in Operation. (courtesy William Warne and Company, Ltd.)*



Neg 0693349-2

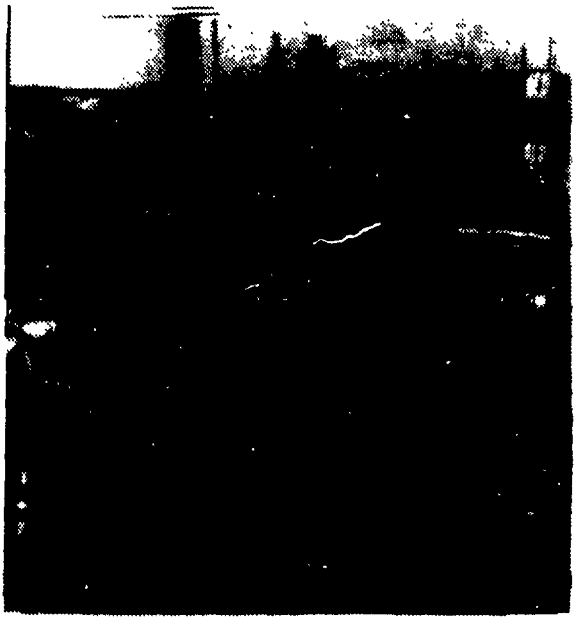
FIGURE D-9. Application of Correxit 7664 Dispersant to a Large Oil Slick (courtesy Enjay Chemical Company)



<u>FIGURE D-10</u>. Oil Vacuum Ring (courtesy Aries Industrial Y Naval, S.A. Madrid, Spain).

D-11

"SLICK SKIM" Model 60



Slickbar Boom
Bridge and Suction Hose

60 gpm Suction Pu

<u>*FIGURE D-11*</u>. *Floating Suction Head/Boom Combination (Courtesy Neirad Industries, Inc.)*

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11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY
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13 ABSTRACT

A cost effectiveness analysis was performed for equipment, materials, and techniques for the removal of spilled petroleum products from the surfaces of ports and harbor waters used by U.S. Naval craft. Effectiveness criteria, formulated for presently practiced methods and available equipment and materials, included speed, completeness, ease of operation, effect on marine life, and availability. Parameters for the effectiveness study were based on the petroleum products now in use or planned for future use and a detailed review of the geographic, hydrographic, physical and environmental characteristics of ports used by the U.S. Navy. It was found that the two most cost effective systems for broad application were mechanical recovery of spilled material by surface suction devices supplemented by mechanical containment and the application of chemical dispersants by pier or vessel mounted high pressure spray equipment. Recommendations included: the development of additional technology pertinent to petroleum product spills of concern to Naval installations; additional management planning and preparation for coping with spill incidents; installation of equipment at Naval facilities to protect sensitive areas; and support of innovative development activities for improved equipment and methods for coping with petroleum spills.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Hydrological Characteristics						
Geographical Characteristics						
Physical Features						
Effectiveness						
Cost Effectiveness						

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